# BAUXITE

CYRIL S. FOX

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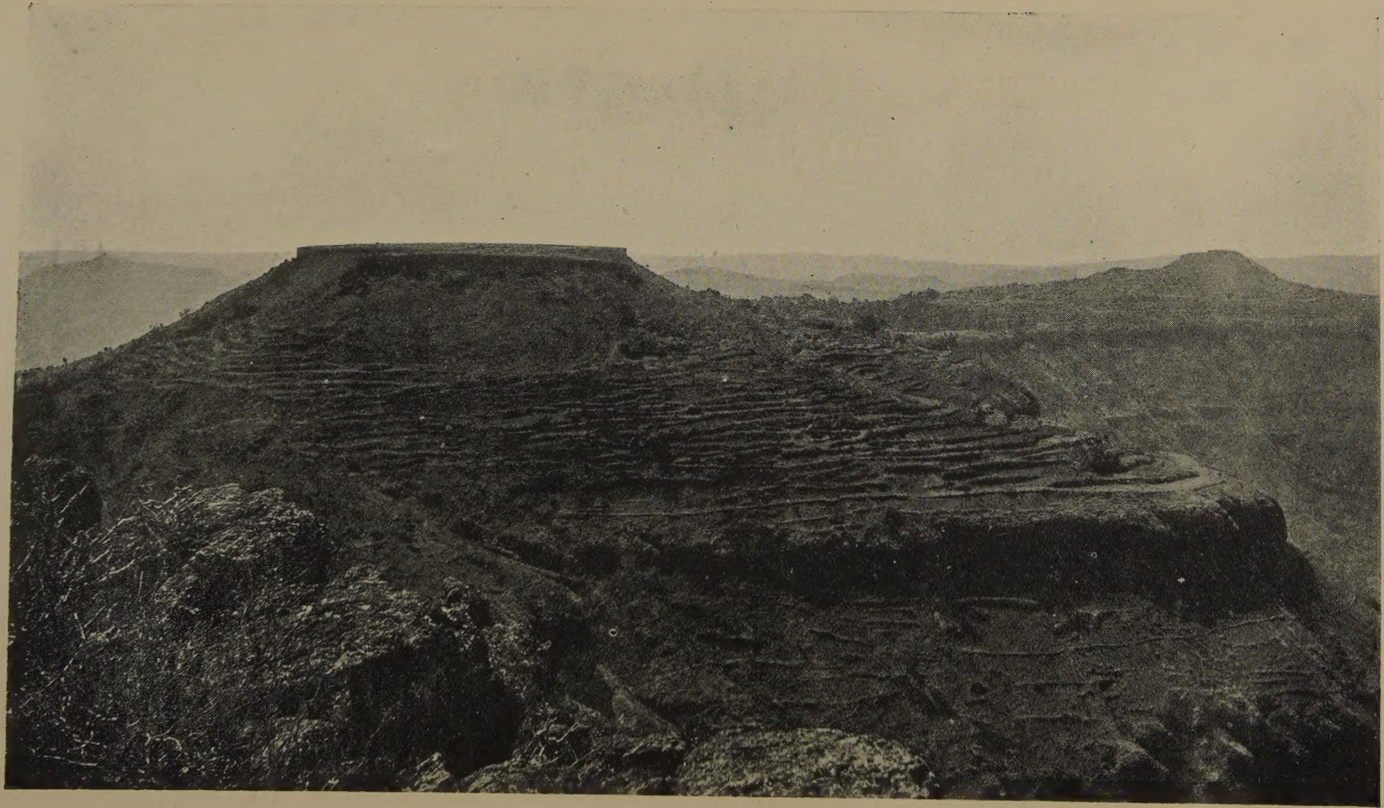
PHOTOGRAPH I.



*With the permission of D.G.S.I.*] [*Photo. by Dr. L. L. Fermor.*

Laterite-capped Plateau on Horizontally Bedded Basaltic Lavas, Panchgani, near Mahableshwar, Bombay Presidency.

# BAUXITE

## A TREATISE

DISCUSSING IN DETAIL THE ORIGIN, CONSTITUTION, KNOWN OCCURRENCES, AND COMMERCIAL USES OF **BAUXITE**; AND INCLUDING PARTICULARS REGARDING THE PRESENT CONDITION OF THE **ALUMINIUM** INDUSTRY AND THE PECULIAR IMPORTANCE OF **CRYOLITE** IN THE EXTRACTION OF ALUMINIUM FROM BAUXITE

BY

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GEOLOGICAL SURVEY OF INDIA

LONDON
CROSBY LOCKWOOD & SON
STATIONERS' HALL COURT, LUDGATE HILL, E.C.
1927

*BY THE SAME AUTHOR*

*Royal 8vo., 160 pp., Illustrated, Net. 10s. 6d.*

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# PREFACE.

In civilised countries it is uncommon to meet anyone who is not more or less familiar with the metal aluminium. Occasionally one encounters otherwise educated people who did not realise that aluminium is as much an element as copper, sulphur, or oxygen are elements. Much more rarely do we meet individuals who know the nature of the ore from which the metal aluminium is extracted. A decade ago bauxite was unfamiliar even by name to most mining engineers and many geologists. These curious blanks in popular and scientific knowledge have in great measure been due to the character of the aluminium industry. Every atom of the aluminium of commerce is to-day obtained from bauxite, and nearly 75 per cent. of the production of bauxite is utilised for reduction to aluminium. The world's output of aluminium, and in some cases aluminium alloys, sheets, rods, etc., is in the grasp of a few companies. The groups who control these companies are countable on the fingers of one hand. The whole organisation is silent, powerful, and effective. The veil which covers their operations in regard to the metal almost entirely obscures the nature and source of its ore. However, I have found that these autocratic producers are perfectly open, consistent with business, and as generous as any other great firms in their dealings with interested enquirers.

In the United States in particular there has been a considerable outcry against the prices demanded for aluminium to-day—prices which prevailed twenty years ago. It is forgotten that there are other commodities of a similar character whose present prices bear a less favourable comparison with their quotations of two decades back. In many ways the slightly acrimonious character of the representations by engineering firms and metallurgical companies who are compelled to pay these prices, is not altogether fair. They know very little of the domestic economy and difficulties which confront

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these producers of virgin metal. Many of these consumers consider that the metal should be produced far more cheaply by existing methods, and in some cases they are devoting their attention to a study of the ore—bauxite.

The element aluminium is more common in the soils, strata and rocky materials of the earth's crust than iron is. It always occurs in a state of combination with other elements, particularly oxygen. Although aluminium is so widespread in rocks and minerals of various kinds, it is in the substance bauxite that we find the most suitable ore from which to extract it. Bauxite has long been used in the chemical industry for the manufacture of alum. During recent years it has been found possible to purify kerosene by simply filtering it through partially calcined bauxite. And, quite lately, the discovery has been made that by fusing bauxite and limestone, and grinding the product, we obtain a cement which begins to set in three or four hours, and in twenty-eight hours becomes harder and stronger than the best Portland cement. Furthermore, this bauxite cement is immune to the action of sea or sulphate-carrying waters. The importance of these properties will be evident not only to an engineer.

There has so far been no single treatise which discusses the world's resources and the economic aspects of a bauxite industry in the detail required. Efforts have been made in this direction, both by the Imperial Mineral Resources Bureau and by the Mineral Section of the Imperial Institute, for the British Empire. Each of these institutions produced valuable publications, but do not appear to have gone far enough, for the "want" does not seem to have been supplied. The metallurgical aspects of aluminium have since been dealt with in a masterly manner by Dr. R. J. Anderson in his classic work, *The Metallurgy of Aluminium and its Alloys*. As soon as this book appeared it became evident that a treatise on bauxite was overdue. There is no man at present who, from personal experience and knowledge, could deal with both the scientific and commercial aspects of bauxite in detail. Such a work must be partly, if not largely, compiled.

In the normal discharge of my geological duties I had for some time investigated the bauxite occurrences of India, and this work was the basis of my report, "Memoir, on the Bauxite and Aluminous Laterite Occurrences of India" (*Mem. Geol.*

*Surv. India*, vol. xlix, part 1, 1923). Later, while on deputation in London, at the office of the Indian Trade Commissioner, in the city, I had opportunities for procuring commercial intelligence. And during this period I was able to visit the reduction works, alumina plant, and bauxite mines of the British Aluminium Co., Ltd., in Scotland, Ireland, and France. It is only natural that I have kept in touch with this interesting industry and fascinating subject, and I have had access to a large part of the current literature. In some cases authors have been kind enough to send me their papers, and frequently they have written. These studies and associations, and the resulting knowledge gained, have given me courage to write this book on bauxite.

As previously noted, the collected information has accumulated in the course of my official work. I take this opportunity for thanking the Director, Geological Survey of India, for his permission to write the manuscript, and I am under an obligation to the Government of India for sanction to publish this book. Needless to say, I am indebted to numerous friends for help of various kinds—most of all to the late Sir Henry Hayden, to whose memory the work is dedicated. I am grateful to Dr. P. J. Brühl for early assistance; to my colleagues, Dr. W. A. K. Christie and Dr. L. L. Fermor, for their advice and criticisms on certain points, and to Mr. W. Murray Morrison for his permission to visit the various mines and works of the British Aluminium Co., Ltd. The late Sir John Harrison from British Guiana, Herr F. von Kerner-Maurilaun in Austria, Herr H. Harrassowitz in Germany, K. Watanabe from Japan, and Dr. R. J. Anderson, Mr. Lloyd T. Emory, and Dr. Poole Maynard from the States, have each sent me published and other information. The Director, Geological Survey of India, Calcutta, the Government Trade Commissioner for British Guiana in London, and the British Aluminium Co., Ltd., have very kindly lent me blocks for the illustrations which appear. The Aluminium Company of America and the Lafarge Aluminous Cement Company, Ltd., of London, have both very kindly supplied me with the particulars I wanted. And, finally, I am sensible of the help, patience, and courtesy which my publishers have shown me.

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# BAUXITE.

## CHAPTER I.

### RELATIONSHIPS OF BAUXITE, LATERITE, AND TERRA ROSA.

OVER a century ago, in 1821, a distinguished French chemist, Monsieur P. Berthier, made the discovery that a certain bed of non-plastic material in the vicinity of Les Baux, near Arles (Bouches-du-Rhone), in Provence, which had been considered as red clay, was not clay at all. Samples obtained from the Les Baux locality contained practically no silica in any form—neither free as quartz nor combined as hydrous silicate. The analysis gave the following components :—

| | |
|---|---|
| Alumina ($Al_2O_3$) . . . | 52·0 per cent. |
| Ferric oxide ($Fe_2O_3$) . . | 27·6 ,, ,, |
| Combined water ($H_2O$) . . | 20·4 ,, ,, |

To this remarkable clay-like substance M. Berthier gave the name *Bauxite*, after the locality from which the first samples were procured. (*Ann. des Mines*, vol. vi, 1821, pp. 531-534.)

M. Berthier's curiosity appears to have been aroused, as to the composition of red clays, by the fact that he had previously (*Ann. des Mines*, vol. v, 1820, p. 129) analysed a peculiar ferruginous material which was reported to occur as a residual weathering-product on rocks in the Futah Djallon territory of West Africa. This substance gave the following analysis :—

| | |
|---|---|
| Silica ($SiO_2$) . . . . | 2·8 per cent. |
| Alumina ($Al_2O_3$) . . . | 8·7 ,, ,, |
| Ferric oxide ($Fe_2O_3$) . . | 77·2 ,, ,, |
| Combined water ($H_2O$) . . | 11·3 ,, ,, |

Whatever may have been M. Berthier's private opinions, he appears to have published none with regard to the possibility of a relationship between the two substances he had examined so soon after each other. It was left to Herr Max Bauer and Dr. H. Warth, separately, nearly eighty years later, to prove conclusively that these two substances are, in many places, varieties of the same kind of rock—the former bauxite, or *aluminous laterite*, and the latter *ferruginous laterite*, or simply laterite.

In 1807 Mr. Francis Buchanan (— Hamilton) had already given the name *laterite* to a remarkable, ferruginous, residual rock which he had met with on his travels through Malabar, Kanara, and the Mysore territories of Southern India. Unfortunately, he recorded no analysis of this substance. He says of it, however :—

> What I have called indurated clay is not the material so-called by Mr. Kirwan, who has not described this of which I am now writing. It seems to be the *Argilla lapidea* of Wallerins I, and is one of the most valuable materials for building. It is diffused in immense masses, without any appearance of stratification, and is placed over the granite that forms the basis of Malayala. It is full of cavities and pores, and contains a very large quantity of iron in the form of red and yellow ochres. In the mass, while excluded from the air, it is so soft, that any iron instrument readily cuts it, and is dug up in square masses with a pickaxe, and immediately cut into the shape wanted with a trowel, or large knife. It very soon after becomes hard as a brick, and resists the air and water much better than any bricks that I have seen in India. I have never observed any animal or vegetable *exuvia* contained in it, but I have heard that such have been found immersed in its substance. As it is usually cut into the form of bricks for building, in several of the native dialects it is called the brick-stone (*Itica cullu*). Where, however, by the washing away of the soil, part of it has been exposed to the air, and has hardened into a rock, its colour becomes black, and its pores and inequalities give it a kind of resemblance to the skin of a person affected with cutaneous disorders ; hence, in the Tamil language, it is called Shuri cull, or itch-stone. The most proper English name would be Laterite from Lateritis, the appellation that may be given to it in science.

The name *laterite* has been applied, both by engineers and geologists, to a similar-looking material in all parts of the world—India, the Strait Settlements, Java, Victoria and Western Australia, South Africa, the Soudan, Sierra Leone and the Congo territories, Brazil, and elsewhere. In India, however, it has been most carefully studied. Laterite was found as a capping or summit bed (see Photograph I). to many of the higher plateaux of the Peninsula (India). It was also recognised, and this was Buchanan's type, in the thick mantle of ferruginous material which is found overlying the rocks of large areas of the country to the south and south-east of the great trap-covered tract of the Deccan. In the former case it had every appearance of having been formed *in situ* by a peculiar kind of sub-aerial weathering of the trap (basaltic lavas). It has been variously designated as "rock-laterite," "high-level laterite," "*in situ* laterite," etc. : terms meant to convey the meaning of *primary laterite*. Its variable iron contents, occasional high alumina percentage, and frequent pisolitic structure were well described by F. R. Mallet in 1883 (*Rec. Geol. Surv. India*, vol. xvi, pp. 103-109). In fact, Mallet went so far as to compare the Indian laterite with the Irish bauxite, and ascribe a similar mode of formation to both (*Rec. Geol. Surv. India*, vol. xiv, 1881, pp. 139-148). Buchanan's laterite, on the other hand, often has a detrital mode of occurrence, an agglomerated structure, and is, obviously, of exceedingly variable composition. Although there is a great similarity in general appearance between this "low level," "detrital," "re-consolidated," or *secondary laterite* and that of the *in situ* or primary type, yet the different varieties can usually be recognised in the Indian occurrences.

The French material, bauxite, was found to be most suitable, among all available aluminous substances, for the extraction of metallic aluminium, and consequently bauxite has now for many years been the only commercial aluminium ore. It was natural, seeing that the relationship between bauxite and laterite was not cleared up till about 1898, that any fresh discoveries of material rich in the hydroxides of aluminium and ferric iron, and of a quality suitable for utilisation as aluminium ore, were recorded as deposits of bauxite. This double nomenclature of laterite and bauxite continued to the close of the last century, when Max Bauer, working in the Seychelles, found both laterite and bauxite in intimate and genetic association, and stated that bauxite must be regarded as a variety of laterite (*Neu. Jahrb. f. Min.*, vol. ii, 1898, pp. 163-219). Sir Thomas Holland had been led to the same conclusion from his study of Indian laterites at about the same time. Much of his data were provided by the (unpublished) analytical work of Dr. P. J. Brühl. However, conclusive proof was soon available when an elaborate research, supplemented by detailed chemical analyses, was published by Drs. H. and F. J. Warth (*Geol. Mag.*, Decade IV, vol. x, 1903, p. 154).

TABLE I.

(Some of Dr. Warth's analyses are shown below.)

| | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|
| Quartz . . . . | — | — | — | — | 10·52 | — |
| $SiO_2$ . . . . . | 2·78 | 0·93 | 3·90 | 0·37 | 0·23 | 0·90 |
| $TiO_2$ . . . . . | 0·04 | 1·04 | 0·38 | 4·45 | 0·20 | 1·59 |
| $Al_2O_3$ . . . . | 62·80 | 67·88 | 54·80 | 43·83 | 35·38 | 26·27 |
| $Fe_2O_3$ . . . . | 0·44 | 4·09 | 13·75 | 26·61 | 34·27 | 56·01 |
| MgO . . . . . | 0·03 | — | — | — | — | 0·20 |
| CaO . . . . . | 0·20 | 0·36 | 0·35 | 0·86 | 0·40 | 0·64 |
| $H_2O$ . . . . . | 33·74 | 26·47 | 26·82 | 23·88 | 19·00 | 14·39 |
| Total . . | 100·03 | 100·77 | 100·00 | 100·00 | 100·00 | 100·00 |

1. Typical Gibbsite. 2. European Bauxite. 3 to 6. Varieties of Indian laterite of the primary type.

Subsequent work has amply confirmed the previous investigations, but there is a tendency to-day to regard the highly ferruginous varieties, chiefly consisting of the ferric hydroxides known as limonite ($2Fe_2O_3 . 3H_2O$), and xanthosiderite ($Fe_2O_3 . 2H_2O$), as laterite, and the highly aluminous types, composed largely of those colloidal hydroxides of aluminium which give an analysis roughly equal to a mixture of gibbsite ($Al_2O_3 . 3H_2O$) and diaspore ($Al_2O_3 . H_2O$), as bauxite. However, in most cases, the mixtures of ferric hydroxides and aluminium hydroxides are present in colloidal form and not as minerals, and the designations bauxite and laterite, therefore, require considerable modification in meaning. Dr. F. W. Clarke (*Data of Geochemistry*, 1920, p. 491), probably the greatest of present-day geochemists, says :—

> Between bauxite and laterite there is no dividing line, and one shades into the other. . . .

He goes on to say that

> the bauxite itself, if we restrict that term to the dominantly aluminous varieties, is probably a mixture of two hydrates, corresponding to gibbsite and diaspore, the latter compound, however, like the gibbsite, being in an amorphous condition.[1]

As a general rule, it is more satisfactory to speak of aluminous laterite, laterite, and ferruginous laterite, according as the samples are obviously aluminous, doubtfully mixed, or clearly ferruginous, and until a chemical analysis has been made to supplement the physical characteristics.

The variable composition of primary laterite, therefore, depends largely on the relative proportions of the two lateritic constituents, the hydroxides of ferric iron and aluminium : usually present in colloidal form. When these constituents are present in about equal amounts, *e.g.* 50 per cent. hydrated ferric oxide ($Fe_2O_3$, 42·75 per cent. ; $H_2O$, 7·25 per cent.) and 50 per cent. tri-hydrate of aluminium ($Al_2O_3$, 32·70 per cent. ; $H_2O$, 17·3 per cent.), the substance would approximate to a typical laterite in composition. If the ferruginous component, *i.e.* the $Fe_2O_3$, exceeds 50 per cent., the rock would constitute an iron ore of the limonite class (or, of a hematite variety if dehydration, which is not unusual, had taken place). On the other hand, if the aluminous, *i.e.* the $Al_2O_3$, percentage is in excess of 50 per cent. the rock would constitute an aluminium ore of the bauxite type. If it were sufficiently free of impurities, silica chiefly, and suitable for the extraction of aluminium, it could be definitely called *bauxite* (*Mem. Geol. Surv. India*, vol. xlix, pt. 1, 1923, pp. 4-5).

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[1] The opinions expressed by Dr. L. L. Fermor in a discussion on D. C. Wysor's paper (*Econ. Geol.*, vol. xi, 1916, pp. 686-690) on the " Aluminium Hydrates in the Arkansas Bauxite Deposits," are of considerable value in connection with the nature of the components of bauxite. Dr. Fermor concludes that—

(1) Wysor's analyses may " be equally well interpreted as indicating mixtures of tri-hydrates and mono-hydrates ; which is the more probable interpretation is a question of evidence. . . . Well crystallised gibbsite is, of course, very commonly found in bauxites . . . but I am not aware that anyone has ever seen in bauxite a single crystalline flake with the properties of diaspore . . . no one has produced a shred of evidence to prove the existence in bauxite of $Al_2O_3 . H_2O$, either crystalline or amorphous . . .

(2) The term bauxite should be omitted from all future text-books of mineralogy as the name of a mineral species, and recognition should be given to the fact that bauxite is a true rock.

(3) Lacroix deduces the probability of the existence of an amorphous colloidal hydrate of titania, and at present it seems reasonable to accept this view, although the microscope does not reveal the separate existence of this substance."

The term bauxite has been used for those varieties of aluminous laterite which are used in the manufacture of chemical compounds of aluminium, aluminous cements, refractories, and abrasives, and for the filtration of kerosene oil. In all these cases chemical analyses are generally available, and so far as data exist, the material utilised is invariably bauxite. There appears to have been some latitude in the use of the term bauxite by geologists (in the field) before assays have been made. This may be convenient, perhaps, because the word bauxite is a little simpler than its equivalent aluminous-laterite, but the practice is liable to lead to misunderstandings as regards commercial quality.

The use of the term " bauxitic " is generally to be deprecated, as it carries with it a certain genetic meaning which is better expressed by the word " lateritic," and any implication as regards composition is far more accurately conveyed by the word " aluminous." For example, we speak of a siliceous-clay when there is silica in excess of the amount necessary to give kaolinite ; consequently the use of the expression bauxitic-clay, instead of the more logical aluminous-clay, when the alumina is in excess of the kaolinite percentage, would seem inaccurate. If the excess of alumina is traceable to the leaching of the silica and other components in the manner in which laterite is formed, *i.e.* under sub-aerial weathering, the correct expression would appear to be aluminous-lateritic-clay.

Dr. Morrow Campbell, in a very valuable paper which is discussed later, prefers the word laterisation and laterise to the corresponding noun and verb lateritisation and lateritise on the ground of simplicity. Dr. Fermor,[1] who is an excellent guide to follow, holds to the stricter nomenclature and keeps the derivation of these two words quite clear. I think his method is preferable.

---

[1] One of the most explanatory papers of recent years in regard to defining the use of the name laterite and, incidentally, bauxite, is from the pen of my colleague, Dr. L. L. Fermor. In this article, " What is Laterite ? " (*Geol. Mag.*, N.S., Decade V, vol. viii, pp. 454-462, 507-516, and 559-566, October-December, 1911), Dr. Fermor terminates his remarks with the following summary (pp. 565-566) :—

" 1. The term *Laterite* is used in two ways, namely, *stratigraphically* as the name of a geological formation, and *petrographically* as the name of a tropical superficial rock. This discussion relates only to the use of the term as a rock name.

" 2. *Laterite* (or rather some varieties of it) is formed by a process, the *modus operandi* of which is not discussed here, by which certain rocks undergo superficial decomposition, with the removal in solution of combined silica, lime, magnesia, soda, and potash, and with the residual accumulation, assisted, no doubt, by capillary action, metasomatic replacement, and segregative changes of a hydrated mixture of oxides of iron, aluminium, and titanium, with, more rarely, maganese.

These oxides and hydroxides of iron, aluminium, titanium, and manganese are designated the *lateritic constituents.*

" 3. This residual rock is *true laterite,* and the presence of any considerable proportion ($>$ 10 per cent.) of non-lateritic constituents requires expression in the name, as it always indicates want of completion in the process of lateritisation. True laterite contains, then, 90 to 100 per cent. of lateritic constituents.

" 4. There is often a gradation in composition between true laterite as defined above and lithomarge, which is taken as the amorphous compound of composition, $2H_2O \cdot Al_2O \cdot 2SiO_2$, corresponding to the crystalline mineral kaolinite of the same composition. For the rocks intermediate between laterite and lithomarge the terms *lithomargic laterite* and *lateritic lithomarge* are available, the former being applied to forms containing 50 to 90 per cent. of lateritic constituents, and the latter to forms containing only 25 to 50 per cent. of lateritic constituents.

" 5. The presence of any considerable amount of quartz, either residual or secondary (this form has not, so far as I am aware, yet been noticed in Indian laterites), should be indicated by terming the rock a *quartzose laterite,* unless the amount of quartz and other non-lateritic constituents exceed 50 per cent., when the word *laterite* should appear only in the adjectival form, as in paragraph 4.

" 6. Many rocks to which the term *laterite* has been applied would be more aptly termed *soils, earths, clays,* and *sands,* with ($>$ 25 per cent.) or without ($<$ 25 per cent. of lateritic constituents) the attributive *lateritic.*

" 7. *Varieties* of the rock defined as true laterite are those in which one of the constituents is present in relatively large amounts, namely, the highly aluminous variety, *bauxite,* the highly ferruginous variety, *lateritic iron-ore,* and the highly manganiferous variety, *lateritic manganese-ore.* From this it follows that alumina cannot be regarded as an essential constituent of laterite, although it is usually present in smaller or larger quantity.

" 8. The property of *hardening on exposure* to the air is characteristic of many varieties of laterite, but it is not an essential property, for some laterites do not exhibit it, whilst cases have been recorded of rocks that show this property and yet cannot possibly be termed laterite, although they probably contain a certain quantity of hydroxides of iron and aluminium, to the hydration of which the setting of laterite is usually ascribed.

" 9. For any rocks (such as some of the *pisolitic limonites*) associated with the laterite formation, that have probably been formed by chemical deposition in lakes or bogs, the name *lake laterite* is suggested. This is regarded as an unimportant variety of laterite.

" 10. Certain lateritic rocks that have been formed by the metasomatic replacement at the outcrops of a variety of rocks, and which cannot be regarded as residual products of the decomposition of the underlying rocks, have been designated *lateritoid.* Such rocks can usually be recognised by their preserving unaltered, or but partly altered, fragments of the underlying rocks, and of retaining signs of the original bedding-planes of the rocks they have replaced. They have hitherto always been found on the upturned outcrops of the quartzites and argillaceous schists and phyllites of the Dharwar formation, and usually take the form of iron-ore or manganese-ore, alumina not being an abundant constituent of the lateritoids.

" 11. Rocks formed by the accumulation of detritus from masses of chemically-formed laterite (or of lateritoid) either alone or mixed with extraneous materials, such as fragments of quartz or gneiss, may be termed *detrital laterites,* as an alternative to which the term *lateritite* is suggested.

" 12. Most of the so-called laterites of the Guianas as described by Harrison

The accompanying Table, II, gives the results of the chemical analysis of typical bauxites from occurrences which are being worked on a commercial scale, or which are being seriously prospected with this object. Certain marked peculiarities will be noticed. Besides differences in the relative amounts of alumina, ferric oxide, and the most serious impurity silica, perhaps the most clearly defined compound is the water of combination. This is particularly true of the percentage of combined water in the bauxites of the Mediterranean region—France, Italy, Rumania, etc.—when these percentages are compared with those of the water in American, African, and Indian bauxites. It might be concluded that the bauxites of the cooler regions have, as a result of pressure due to overlying strata, undergone partial dehydration. This explanation may require modification, as it is also thought that the differences are essentially due to the mode of origin. The non-European types of bauxite, except for some exceptions in the United States and the peculiar occurrence in Jammu (India), are of a lateritic origin. None of these lateritic bauxites are considered to be older than the Tertiary period of geological time. With regard to the Mediterranean and Appalachian —the so-called "terra-rosa" type—which, of course, do not include the bauxites of Antrim (Ireland) and Hesse (Germany), opinions differ. The ascribed ages vary from Triassic to early Eocene, where stratigraphical evidence is obscure, but there is a growing conviction that the date of formation was subsequent to the Lower Cretaceous period.

Continental workers, more especially Kispatic, Tucan, Kerner-Marilaun, etc., in the Balkan regions of the Adriatic littoral, and Arsandaux in the south of France, appear to have come to the conclusion that the red, pink, and white bauxites of their areas are related, genetically, to the *terra rosa* (or *roterde*) now found over limestone regions on the Mediterranean seaboard. This *terra rosa* is the clayey residue which is left when certain limestones and dolomites are exposed in bare uplands (Karstlands) to atmospheric weathering and slowly dissolved away. (See *Geologie der Bauxitlagerstätten des südlichen Teiles der österreichisch - ungarischen Monarchie*, Wien, 1916, by Kerner-Marilaun.) F. Katzer (see *Die Eisenerzlagerstätten von Bosnien und Herzegowina*, Wien, 1910,

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and Du Bois are not true laterites unqualified, but are either *quartzose* or *lithomargic laterites*, or *lateritic earths*. Many of them are detrital rocks, sometimes rich enough in lateritic material to be called *detrital laterite* or *lateritite*. True laterites do, however, also occur.

"13. The classification of laterites and associated rocks put forward in this paper is, of course, of a more or less tentative nature, and although it is believed to be a workable system of nomenclature, yet future work will doubtless show the desirability of various modifications and amplifications."

## TABLE II.

### Analyses of Characteristic Bauxites.

| | France. | | | | Rumania. | | Dalmatia. |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1. $SiO_2$ . . | 0·80 | 0·80 | 0·29 | 13·3 | 1·49 | 0·80 | 0·89 |
| 2. $TiO_2$ . . | 2·80 | 3·50 | 0·80 | 2·4 | 3·12 | 2·80 | — |
| 3. $Al_2O_3$ . | 58·6 | 76·4 | 60·60 | 63·7 | 59·66 | 65·5 | 51·85 |
| 4. $Fe_2O_3$ . | 26·2 | 4·8 | 26·0 | 5·5 | 23·66 | 21·3 | 26·82 |
| 5. CaO . . | — | — | — | — | — | — | — |
| 6. MgO . . | — | — | — | — | — | — | — |
| 7. $H_2O$ (comb.) | 10·9 | 14·3 | 10·4 | 14·3 | 11·81 | 9·96 | 19·97 |

| | Italy. | | United States. | | | | British Guiana. | | India. | | | Gold Coast. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 1. $SiO_2$ . . | 2·79 | 7·91 | 2·90 | 2·00 | 10·13 | 0·62 | 2·73 | 1·00 | 1·18 | 1·44 | 0·30 | 1·72 | 0·62 |
| 2. $TiO_2$ . . | 1·27 | — | 3·40 | 3·50 | — | 1·05 | 0·10 | 1·10 | 8·80 | 6·32 | 7·40 | 1·89 | 1·66 |
| 3. $Al_2O_3$ . | 57·6 | 58·85 | 58·21 | 62·05 | 55·59 | 64·91 | 64·38 | 70·90 | 60·23 | 62·32 | 66·98 | 64·40 | 59·05 |
| 4. $Fe_2O_3$ . | 26·55 | 18·62 | 3·60 | 1·66 | 6·08 | 0·28 | 0·50 | 0·80 | 2·64 | 2·65 | 5·92 | 2·27 | 12·19 |
| 5. CaO . . | — | 0·30 | — | — | — | — | — | — | 0·82 | Trace. | — | — | — |
| 6. MgO . . | — | 0·37 | — | — | — | — | — | — | 0·30 | 0·38 | Trace. | — | — |
| 7. $H_2O$ (comb.) | 11·71 | 13·27 | 31·89 | 30·31 | 28·99 | 33·00 | 32·29 | 26·30 | 25·40 | 26·27 | 21·40 | 29·24 | 26·47 |

1 and 2. Loupain (Herault), analyses by M. Blot for M. Arsandaux. 3 and 4. La Caire (Var), analyses ditto. 5. Cucul (Bihar Mts.), analysis by M. Blot for R. Lachmann. 6. Dealul Cruci (Bihar Mts.), analysis ditto. 7. Dernis (Dalmatia), analysis by Kucan for Kispatic. 8. Lecce dei Marsi (Abruzzo), analysis given by G. Aichino. 9. Pietraroja, Benevento (Campagna), analysis given by Mattiralo. 10. Cherokee Co. (Alabama), analysis given by H. McCalley. 11 and 12. Arkansas, analyses given by J. C. Branner. 13. Floyd Co. (Georgia), analysis given by T. L. Watson. 14. Yarikita River (British Guiana), analysis given by J. B. Harrison. 15. Essequibo River, analysis ditto. 16. Bargawan hill (Katni), Jabalpur District, analysis by R. V. Briggs. 17. Panhala Fort, Kolhapur State, analysis by R. V. Briggs. 18. Rajadera, Ranchi District, analysis Geological Survey of India, Laboratory. 19 and 20. Mt. Ejuanema Bauxite (after A. E. Kitson).

p. 331) is, however, not in agreement with this view. He thinks that the bauxites of the Balkan region are the direct residue of silicate minerals derived from igneous rocks which lie at a considerable distance, or are now covered by sedimentary deposits.

The general opinion, which regards the bauxite of the Balkans as "fossil terra rosa," if correct, brings in its train many points of importance. The residual mud or slime from the original limestones would be left behind in crevices, solution channels, and pockets in the rock itself. It would also be carried away in suspension and deposited in layers like other sediments. Over and above these peculiarities there is to be considered the intense folding and thrust faulting to which the whole North Mediterranean region has been subjected since the bauxite was deposited. With these factors, duly considered, a full explanation can be advanced for all the complexities of occurrence met with in the mining of these Balkan bauxites.

If, therefore, Kispatic is correct in his conclusion, *i.e.* that *terra rosa* is the insoluble residual slime from certain limestones, and consists of finely disseminated aluminium hydroxide and ferric oxide both in *gel*[1] form, in the parent rock mass, then the differences between *terra rosa* and present-day laterites are not very great. In both types the weathering processes of solution have removed certain soluble constituents and left behind material of similar composition. In the case of *terra rosa* the residue is an impervious mud or slime which occupies a small fraction of the bulk of the original rock. In the case of laterite there is no diminution in volume, but the texture of the residue is a massive porous rock. Furthermore, the combined water in the *terra rosa* material is small, *i.e.* 10 per cent. or so, while in the laterite the percentage of combined water is higher, *i.e.* 20 per cent. and over.

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[1] The nomenclature of colloids used follows that given in *The Chemistry of Colloids*, 1915, by W. W. Taylor. Colloids in contrast to crystalloids do not crystallise, and have a slow rate of diffusion. They do not appear to be able to pass through permeable septa such as are used in experiments on osmosis or capillary pressures. It was suggested by Graham that the colloidal molecules may be constituted by a special arrangement, or grouping together, of a number of smaller crystalloidal molecules.

Colloids evidently occur in two conditions, as *sols*, in which the substance is apparently liquid or contains much liquid matter in combination, and as *gels*, the jelly-like form in which there is a smaller proportion of contained liquid matter. If the liquid is water the terms *hydrosol* and *hydrogel* are used.

These two states of colloidal matter may exist in actual liquid or solid particles or phases, and may be contained in two extreme states of dispersion in liquids as emulsions and suspensions (less concentrated).

The reversible transformation *sol* $\rightleftarrows$ *gel* is important. A *sol* may gelatinate to a *gel* while a *gel* can become a *sol*. The *gel* does not dissolve to become a *sol*—if the *gel* dissolves it passes into solution, the action is one of absorption. A *gel* solates.

These colloidal particles move in an electric field, and are considered to be electrically charged. In some cases the particles are positively charged, and in others they are negatively charged. Under certain conditions it is possible so to change the potential that positively charged particles appear to be negatively charged, and *vice versa*. Positive *sols* meeting with negative *sols* precipitate as *gels*.

Colloids * comprise all matter that is made up of particles smaller than a wave-length of light, but larger than a single molecule of an ordinary crystalloid substance, such as sugar, salt, or water. It would appear that in some cases the chemical molecules are linked together into particles of colloidal dimensions, and then from

(* "Colloids and Colloidal Electrolytes," by J. W. McBain, *Nature*, 10th March, 1921.)

The very probable genetic relationship between the *terra rosa* of the Mediterranean littoral and the bauxites of the North Mediterranean region, and, as a parallel case, the bauxites of the Appalachian area in the U.S.A., leads to a very serious difficulty in discussing the subject of bauxite generally. It would appear evident that there are at least these two modes of origin for bauxite :—

(*a*) The **terra-rosa** type, where the bauxite represents an exceedingly small insoluble fraction of what was a great mass of soluble limestone or dolomite ; and which was (1) primarily *deposited* in sheets or irregular cavities, when first liberated, and which may be subsequently eroded ; and (2) *redeposited* with other sediments ; and

(*b*) The **laterite** type, where the bauxite remains on the locality of the original aluminous rock, of which it represents the greater part (by volume), and is consequently (1) also a primary or *in situ* occurrence, which is also capable of being eroded ; and (2) *redeposited* as detrital or secondary material.

A solution to this difficulty of classification may be arrived at if we follow a local classification adopted by F. R. Mallett (*Rec. Geol. Surv. India*, vol. xvi, 1883, pp. 116-118). In discussing the origin of certain manganese ores (pyrolusite with psilomelane) in the laterite of Gosalpur, Jabalpur district, C.P., India, Mallett, who believed in the theory of laterite formation in lakes, was forced to the conclusion that that explanation would not prove universal, and with the facts before him classified three forms of laterite as due to :—

(1) Alteration of rock *in situ ;*
(2) Due to deposition ; and
(3) Detrital or redeposited laterite.

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these particles are built up the familiar structures such as rubber, fibres of cotton, wood, or earthenware. A very important characteristic of most colloidal solutions is the fact that the colloidal particles possess electrical charges, and calculation shows that on each such particle there are anything up to 100 million negative charges or electrons. This electrical charge seems enormous, but it is relatively ever so much less than the number of atoms, and in an ordinary *ion* there is one electrical charge for each atom.

If the above plan is accepted, our phraseology will have to be guided accordingly. We may speak of *deposits of bauxite* with regard to classes (2) and (3), but not so with (1). In this case, *i.e.* (1), we must speak of *occurrences of bauxite.*

It will be convenient to adopt this general classification, and in cases of doubt to remember that (1) is invariably characterised by a high combined water percentage, varying from 19 to 32 per cent. ; (2) is seldom found to contain less than 8 or more than 14 per cent. combined water ; and (3) is frequently characterised by rounded grains of quartz and other, evidently derived, substances.

# CHAPTER II.

## MODE OF OCCURRENCE IN VARIOUS COUNTRIES.

### UNITED STATES OF AMERICA.

CONSIDERABLE occurrences of bauxite occur and have for many years been worked in the United States, particularly in Arkansas, Georgia, Alabama, and Tennessee, and, to a lesser extent, in other States.

**Arkansas.**—In this area there are two chief occurrences of bauxite: (1) at Bauxite; and (2) near Little Rock. Both *primary* and *detrital* varieties of bauxite have been found. The primary ore occurs in bedded masses, averaging 11 feet thick, in association with lithomarge, and overlying kaolinised nepheline-syenite. It is thought that this bauxite is the residual weathering product of lateritised nepheline-syenite; because it contains various minerals—"zircon, the rare felspar celsian ($BaAl_2Si_2O_8$), pyrite, barytes, and fluorspar, all of which are accessory minerals in the underlying syenite." (W. G. Rumbold, *Bauxite and Aluminium*, 1925, p. 93, Mono. Imp. Inst. See also W. T. Mead, "Occurrences and Origin of Bauxite Deposits of Arkansas," *Econ. Geol.*, vol. x, 1915, pp. 28-54.)

W. J. Mead

The upper part of the primary bauxite is pisolitic and of a pink to buff colour. Downwards this pisolitic ore passes insensibly into a "sponge" or "granitic" ore, which very clearly retains the texture of the original syenite. The primary ore is in places covered by alluvial beds of gravel and sand, which constitute the overburden which has to be removed in the process of quarrying.

The detrital ore is interstratified with beds of Tertiary age. It is sometimes so mixed with these sedimentary sands, etc., as to be unprofitable to work. The upper layers of the bauxite are said to be often contaminated with secondary silica: occasionally to such an extent that the top 18 inches or 2 feet has to be discarded. Analyses of these Arkansas bauxites are given elsewhere (pp. 8 and 109.)

**Georgia.**—In Central Georgia lenticular, horizontal beds of bauxite—associated with lithomarge, which is both intercalated with and underlies the bauxite—occur in Wilkinson, Twiggs, Washington, and Baldwin counties. In some cases the denuded remnants of these bauxite lenses occur as small boulder accumulations on the surface. Most of the material is in nodules or pisolites. The presence of such constituents as zircon, apatite, pyrite, and ferromagnesian minerals, is suggestive of the bauxite being the residual product of the sub-aerial weathering of pre-Cambrian igneous and metamorphic rocks which are exposed in this region. O. Veatch ("The Bauxites of Wilkinson Co., Georgia," *Geol. Surv. Georgia*, 1909, Bull. No. 18, pp. 430-447), on the other hand, considers his field evidence to prove that the bauxite has resulted from the alteration of kaolin and other clays by the action of alkaline meteoric waters.

The bauxite horizon is intimately related with a *stratigraphical break*, which appears to have involved rocks of Cretaceous age. These beds rest unconformably upon pre-Cambrian gneisses, and are in turn overlaid by sediments of Tertiary age, thereby indicative of a late Cretaceous to early Tertiary age for the bauxite beds.

In the McIntyre mine (Wilkinson Co.):

> "The bauxite occurs at the top of the Cretaceous beds, and is overlaid unconformably with Lower Tertiary sands and clays. Its shape is lenticular; downwards it merges into kaolin, and the upper surface is pitted with "pot-holes" filled with Lower Tertiary clays. The average thickness of the payable ore, which is of the pisolitic type, is 5½ feet. Open-cut mining methods are used, an average depth of 10 feet of overburden having first to be removed." (W. G. Rumbold, *Bauxite and Aluminium*, 1925, p. 98; see also paper by O. Veatch, *op. cit.*, and W. C. Phalen, "Bauxite and Aluminium in 1908," *U.S. Geol. Surv., Min. Res. U.S.*, pt. 1.)

In Mid-West Georgia, Meriweather Co., bauxite occurs on the northern slope of Pine Mt., in association with kaolin beds (thought to be of Cretaceous age), which overlie a schistose quartzite.

The bauxite of North-West Georgia occurs in irregular deposits in association with lithomarge (kaolinite and siliceous clays) in the Hermitage, Bobo, and Summerville districts. The underlying rocks are a greatly disturbed series of older Palæozoic beds:—

3. Knox Dolomite, a massively bedded, grey, semi-crystalline, siliceous, magnesian limestone, 3000 to 4000 feet thick (Cambro-Ordovician age).
2. Connasanga Shales, which are aluminous at their base, 3000 to 4000 feet thick.
1. Weisner Quartzites (Cambrian age).

The bauxite and lithomarge overlies all horizons of the Knox dolomite, and segregations of silica as chert are found often in the dolomite. The bauxite and lithomarge appears to be residual material, either from the dolomite itself or from some other source. In the Hermitage district the dolomite is horizontal. In the vicinity (3 miles from) of Hermitage Furnace the pisolitic to vesicular bauxite bed at Holland Bank has a circular outcrop, 100 feet in diameter, in the middle of deep red clays (T. L. Watson, "Bauxite Deposits of Georgia," *Geol. Surv. Georgia*, Bull. No. 11, 1904, pp. 58-61). In the Bobo district a cream-coloured coarsely pisolitic bauxite is associated with a cherty residual clay, which overlies the Knox dolomite. These Palæozoic limestones dip steeply eastward, and are traversed by faults. The bauxite deposits appear to follow the strike of these faults in a manner suggestive of some genetic relationship. Again, at Taylor's Bank, in the Summerville district, a fault separates the Knox dolomite from the Connasanga shales, and, evidently connected with this fault, there is a development of bauxite. The occurrence is peculiar in that boulders of a grey pisolitic and vesicular bauxite lie in a matrix of soft, white lithomarge. This amorphous clay lies as a vein, or lens—60 feet long by 12 to 18 feet wide—along the line of the fault. Carbonaceous matter in small quantities is associated with the bauxite. (See Watson's paper, *supra.*)

**Alabama.**—Bauxite of Cherokee Co., near Indian Mt., Dyke district, also occurs in association with the Knox dolomite, which is here greatly crushed and faulted. Again the bauxite deposits occur along the line of a fault—that between the Knox dolomite and the sandy shales and quartzites of Indian Mt. The ore body at Taylor's Bank mine consists of angular fragments of coarse pisolitic bauxite, with ferruginous gravel ore, in a matrix of white and red mottled clay. (W. G. Rumbold, *op. cit.*, 1925, p. 96.)

**Tennessee.**—Bauxite is worked at the Perry mine, Sherman Heights (Missionary Ridge), in the Chattanooga district, and at the Gibson mine, Holston Mts., in the Keenburg district. The ore is of two varieties : (1) The hard bauxite is called "dornick," and (2) the soft material is "block ore." In the latter area the bauxite is again associated with lithomarge. It occurs as a residual deposit on shales (Watanga) of Cambrian age, and closely follows the line of a fault. (W. C. Phalen, "Bauxite and Aluminium in 1913," *U.S. Geol. Surv., Min. Res. U.S.*, pt. 1, 1914.)

**Other States.**—Bauxites of low grade, or in small deposits, have been located in Southern Virginia as

> "scattered masses in variegated clays 15 to 30 feet thick lying on decomposed Cambrian sandstone or quartzite, and near the contact of the Lower Cambrian quartzite and the overlying Cambrian limestones and shales." (W. G. Rumbold, *supra*, p. 97 ; also W. C. Phalen, *op. cit.*, 1908.)

Small deposits of low-grade bauxite have been found in Pontotac, Tippah and Benton counties, in the State of Mississippi. They are associated with clays and lie irregularly scattered along a belt of hills of Eocene (Wilcox formation) strata.

From the above details it would appear that there are two quite different modes of origin for the bauxite of the United States. Those of Arkansas and Central Georgia would appear to be of the true laterite type, formed by the sub-aerial weathering (lateritisation) of nepheline-syenite ; while the bauxites of the Appalachian area—*i.e.* North and Mid-West Georgia, Alabama, Tennessee, and Virginia—are intimately related with dolomitic limestones. In both cases, judging by the associated Tertiary strata, and the very considerable tectonic disturbances which had folded, faulted, and crushed the older rocks, the age of the bauxite formation would appear to be subsequent to the deposition of beds of Cretaceous age. The manner of occurrence of the bauxite in the Appalachian area is highly suggestive of chemical action—possibly simple solution of the dolomite : whereby the clays (lithomarge) and bauxite—original impurities in the siliceous but not markedly ferruginous limestone—are residual products after the limestone has been dissolved away. Such an origin would entail that the Appalachian bauxites should be included as a class of the "terra-rosa" type of European bauxites. This is an assumption, however, and one which is open to several objections. The actual composition of the Knox dolomite has not been stated. Nor has the character of the associated lithomarge been truly determined. Finally, the true nature of "terra-rosa" has yet to be satisfactorily elucidated.

In the opinion of several American geologists the North and Mid-West

> "Georgia deposits are regarded as being derived by solution of alumina from shales, transportation upward by ascending solutions and deposition as irregular bodies in dolomite and limestone. The occurrence of the bauxites of Alabama and Tennessee is similar to that of the Georgia ores." (R. B. Ladoo, *Non-Metallic Minerals*, 1925, p. 81.)

In support of the terra-rosa theory, it must be urged that the deposition of a residual slime would also occur in the subterranean channels of underground waters, *i.e.* along, or in the vicinity of, fault planes and joints and fissures.

## South America.

Laterites have long been known to occur in the coastal region from the mouth of the Orinoco in Venezuela almost to the Amazon. Workable beds and bodies of bauxite have been found with the laterite in British Guiana (Demerara), French Guiana (Cayenne), and Dutch Guiana (Surinam) in this littoral tract. Inland lateritic bauxite has been found in Minas Geraes (Brazil). The mode of formation of the Guiana bauxite (laterites) is thought to be exactly similar to that of the laterite of India. The age of laterite formation in these South American territories is considered as subsequent to the close of the Mesozoic period of geological time. However, the land region underwent submergence since the bauxite was formed, and alluvial material has in many cases been deposited on the bauxite. Within relatively recent times the area has been slowly raised from the sea, and the alluvial beds, together with the underlying bauxites, are being eroded by the existing rivers.

PHOTOGRAPH II.

[*Per favour: G. T. C. for British Guiana.*

The Kaieteur Falls. Vertical drop 741 feet.

**British Guiana.**—A full report dealing with the bauxite occurrences of the colony has been prepared by Sir John Harrison. He shows the lateritic bauxite to be the residual weathering product of altered dolerite (diabase) and other basic rocks. The primary bauxite is associated with an underlying lithomarge as in the Indian occurrences.

> "The most extensive deposits at present known are situated in the Christianburg-Akyma district of the Demerara River. These deposits extend along the banks of the Demerara River from Plantation Christianburg on the north (situate 75 miles from the mouth of the river) upwards to Akyma and Komaru in the south, a distance of 10 miles as the crow flies, and are in places of considerable thickness, possibly from 30 to 40 feet." (*Handbook of British Guiana,* 1922, pp. 116-117.)

The bauxite varies in colour from pink and cream to mottled varieties, with red streaks. The texture is normally of a finely granular character, suggestive of a somewhat porous, non-plastic, loamy clay. Pisolitic and vesicular structures occur. The material is generally soft, and can easily be dug by hand. The water content is high, and the quality of the ore is excellent. Analyses are given on another page (118).

The mode of occurrence of the bauxite in Surinam and French Guiana is the same as it is in British Guiana—the bauxite is similar, but evidently not quite so extensively developed.

## Africa.

Laterite has been found chiefly in the coastal hinterlands of West and East Africa—in the former region from north of French Guinea, across Sierra Leone, round by the Ivory Coast and the Gold Coast, through Togoland and Nigeria to the Cameroons, and the Congo: in the latter region from Somaliland, through the Tanganyika territory, to Nyassaland and Rhodesia. Laterite is not unknown in Central Africa. It occurs in the Katanga district of the Belgian Congo and in the Sudan region to the north of the Lakes. The laterites of the islands of the Indian Ocean, Madagascar, the Seychelles, etc., are also well known. In spite of the great regions throughout which laterite is found, it is curious that bauxite segregations of workable size are uncommon. Occurrences have been located at Siguiri and elsewhere in the Niger territory of French Guinea, the Akem Province of the Gold Coast and French Togoland in West Africa; and in Nyassaland, and at Amani (Usambara) in Tanganyika territory, East Africa. In the majority of cases, as in the tracts of West Africa traversed by Professor A. Lacroix, the bauxite is generally derived from the lateritisation of some variety of igneous rock—nepheline-syenite at Kassa, and dolerite (diabase) at Bongouron Mt., in the Futah Jallon area of French Guinea; granite and diorite in the Seychelles; and from similar rocks in Madagascar. It is common to find *exposures* of better quality bauxite associated with the more acid types of igneous rock, but this generalisation requires considerable qualification when we review the mode of occurrence of the *workable* masses of bauxite throughout the world. In such a survey it will be discovered that few workable bauxites are found in association with granitoid rock. The biggest occurrences of bauxites, of the laterite type, are derived from basic rocks. There are a large number of important bauxite deposits of the so-called "terra-rosa" type which are genetically related to limestones. Two new and remarkably interesting occurrences have been found in the Gold Coast by Dr. A. E. Kitson.

**Gold Coast.**—In this colony there are two particularly attractive occurrences of lateritic bauxite: (1) Mt. Ejuanema on the Kwahu plateau, and (2) Mt. Supirri, further to the west. In the former area the bauxite appears to have resulted from the lateritisation of certain shales. These are associated with the horizontally bedded sandstones and shales that overlie the basal granites of the Kwahu plateau. The bauxite, which is sometimes massive and frequently rubbly, and of a finely granular texture, averages about 19 feet thick, and is not overlaid by alluvial deposits. A curious feature of this bauxite is the large amount of carbonic acid gas which is emitted when pits are sunk into the rock. The nature of the gas suggests a calcareous (carbonate) shale as the original rock which had suffered lateritisation.

The other occurrence, at Supirri and neighbouring hills, contains a more ferruginous bauxite (laterite). Here the material appears to have resulted from the lateritisation of the steeply inclined phyllites and mica schists. These metamorphic rocks contain veins and strings of quartz, frequently carrying payable percentages of gold and silver. It is, therefore, interesting to discover that not only are undigested streaks of quartz and fragments of undecomposed rock present in the covering laterite, but that gold and silver in payable amounts also occur. Incidentally, these impurities, valuable in the case of the gold and silver, in the laterite give clear evidence of the mode of formation and origin of the laterite.

## AUSTRALIA.

Laterite occurs in various parts of this great island continent—in Western Australia, South Australia, Victoria, New South Wales, Queensland, and in the Northern Territory. In the majority of cases, except for mere interesting exposures of bauxite, the material is either too ferruginous (laterite) or too siliceous (lithomarge) to be usable as bauxite, although the high alumina percentage must give it a commercial value, either for refractory purposes or in the preparation of aluminium salts.

**New South Wales.**—Bauxite of attractive quality is found in two areas—(1) near Wingello, Camden Co.; and to the north (2) in the Emmaville and Inverall districts. The material occurs as a surface capping to several small hills, and appears to have been derived from the lateritisation of basalt. It is pisolitic to massive, and has a pseudo-bedded structure. (E. F. Pittman, "Aluminium," *N.S.W. Dept. Mines Geol. Surv., Min. Res.*, 1901; also an anonymous article, "Bauxite Deposits," *Ind. Aust. and Min. Stand.*, 15 Oct., 1921, p. 462.)

**Northern Territory.**—An interesting occurrence of a pisolitic, siliceous to ferruginous, bauxite has been found capping the tableland of Roe Mt. (488 feet), and another hill, Mt. Bidwell (426 feet), in the Coburg Peninsula. The composition of the rock is: $SiO_2$, 21·00 per cent.; $Al_2O_3$, 47·32 per cent.; $Fe_2O_3$, 9·74 per cent.; and $H_2O$, 22·32 per cent. The material consists of agglomerated red and white ferruginous pisolites in a mantle, said to be 50 feet thick. It is evident that the name of the mountain was obtained from the roe-like aspect of the rock. The underlying strata are horizontally bedded, and consist of ferruginous sandstone, ironstone, ferruginous shale and sandstone (downward). It is not stated what type of rock has been involved to produce the pisolitic bauxite.

**Western Australia.**—Lateritic bauxite and ferruginous laterite occur on the Darling and Blackwood Ranges. The material varies from pisolitic to vermicular in texture, and of variegated mottled red, brown, and pink colours. The more aluminous types are usually traceable to the lateritisation of granitic or other acid igneous or gneissic rocks, whereas the ferruginous types are genetically related to basic rocks, *e.g.* amphibolite, diorite, etc.

## EUROPE.

All the bauxite occurrences in Europe are found interstratified or in irregular pockets in bedded rocks, sometimes with basaltic lavas, but more frequently in association with limestones. In the case of the intertrappean bauxites of Antrim (Ireland) and Hesse-Nassau (Germany), the related basaltic lavas are known to be of early Tertiary age, and the bauxites, it is thought, could not have been formed earlier than the lower Miocene period. In neither of these areas have the rocks suffered severe dynamic-metamorphism, and the beds lie practically horizontal and undisturbed. With regard to the bauxite beds of France, Italy, Jugo-Slavia, and Rumania, the associated strata range in age from lower Eocene and upper Cretaceous down to those of Triassic age. The mode of formation of these bauxites is not clearly understood. The containing rocks appear to have suffered considerably from tectonic disturbances—folding and faulting—since Eocene times, *i.e.* in most cases after the bauxites were formed. In nearly all these areas the European bauxites resemble a stiff, non-plastic clay in appearance and texture.

The material generally has a chocolate or mottled pink to cream or white colour, and is soft and easily mined. Pisolitic varieties of all colours are common, but the most frequent are the reddish to pink varieties. These bauxites are thought to be the residual sub-aerial weathering product of limestones. Consequently the occurrence of bauxite at any horizon is assumed as geological evidence of a " stratigraphical break "—a cessation in the deposition of sediments, etc., in that region during the interval.

**Ireland.**—The Tertiary lavas of Antrim have been divided into two divisions, thus :—

Upper Basalts ;
Intertrappean beds with lignite beds, pisolitic iron ore, bauxite, lithomarge, and associated intrusive rhyolite ; and
Lower Basalts.

They are, as shown, separated by an intertrappean zone 80 feet thick. Normally such intertrappean beds contain layers of red clays (bole). In this case the Lower Basalts, after they were intruded by rhyolite dykes and sills, appear to have suffered partial lateritisation. As a result their upper zone, including the rhyolite, wherever involved, was altered to kaolinite, bauxite and iron ore (*upwards*). These residual products occur in the positions where they were formed. The Upper Basalts were evidently erupted long after the process of lateritisation had been arrested. The presence of the lignite beds above the laterite suggests that the elevated laterite surface was gradually converted into marsh-lands. This incomplete lateritisation is abundantly evident from the siliceous nature of the bauxite as a whole. The material extracted from the Tuftarney mine is, for this reason, at present only usable for the manufacture of aluminium salts. Professor Grenville Cole has expressed the view that, whereas *most* of the Irish bauxites originated from the lateritisation of basalt, *those* of Glenarm (Cullinane) and Straid (Irish) Hill have resulted from the alteration of rhyolitic material. (" Interbasaltic Rocks of N.E. Ireland," *Mem. Geol. Surv. Ireland*, 1912.)

**Germany.**—The bauxite occurrences of Hesse are similar to those of Ireland. The aluminous ore occurs either as surface nodules or embedded in lithomarge, and is evidently the residual weathering product of basaltic lavas. (J. R. Kilroe, " On the Occurrence and Origin of Laterite in the Vogelsberg," *Geol. Mag.*, Decade V, vol. v, 1908, p. 534. See also Hermann Harrassowitz (*née* H. L. F. Meyer), " Die Bauxitlagerstätten des Vogelsberges," *Metall und Erz*, xviii (N.F. ix), Jahrg. 1921, Heft 22.) Owing to the poor quality of these bauxites they, like the Irish ores, are seldom in great demand for the aluminium industry.

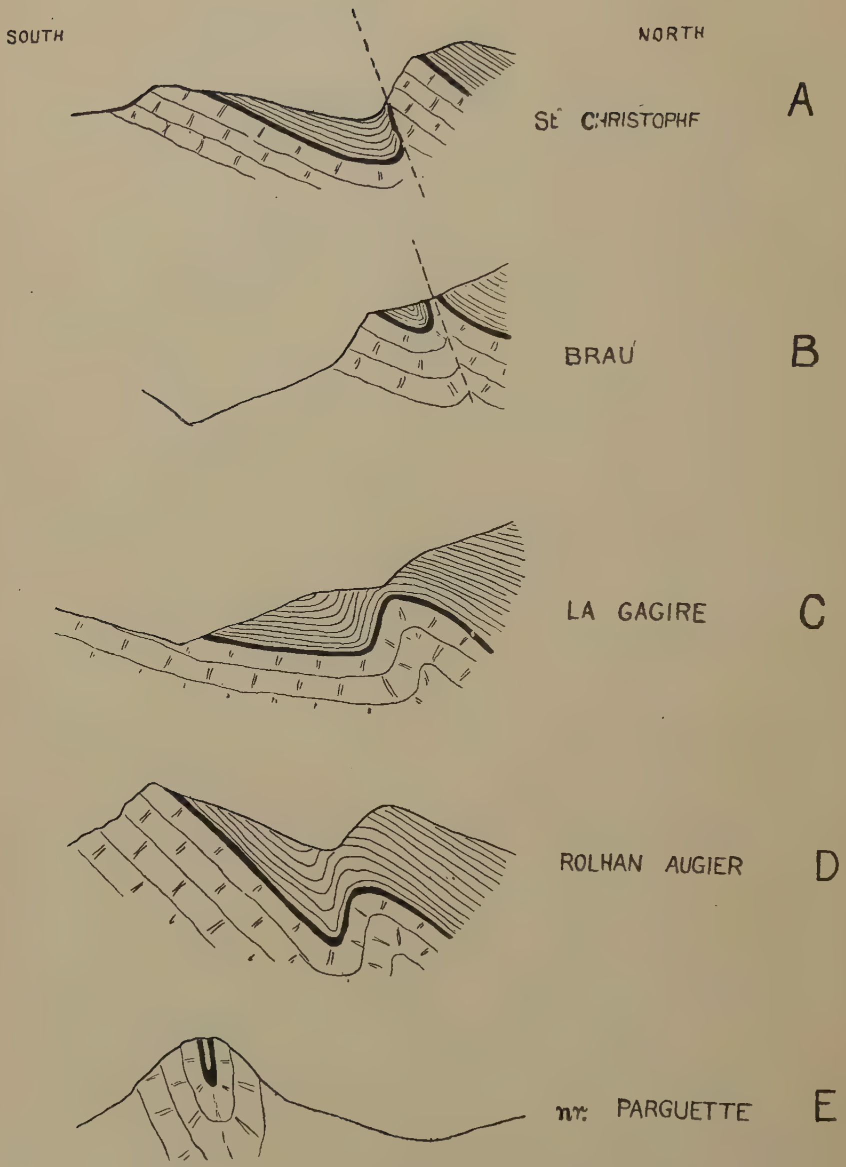
**France.**—In the coastal region in the south of France, throughout Languedoc and Provence, there is evidence of a great " stratigraphical break" between the Upper Jurassic (also partly Lower Cretaceous) and Upper Cretaceous formations. In this interval of geological time much of the land was dry land, and the deposits on it were of a fresh-water type. The bauxites of the Ariège, Hérault, Bouches-du-Rhone, and the Var appear to have been formed during this great interval (Aptian to Gault). The sheet-like deposits of bauxite, often intercalated with certain lacustrine beds (Leymerie's Garumnian stage), are found lying transgressionally over various marine stages of the Infra Lias, and upper beds, to those of Neocomian age, and they are covered by fresh-water strata of the Cenomanian to Danian epochs. It is concluded from these facts that the bauxites of the south of France were formed during the period Aptian to Gault. The mode of formation suggested is that the bauxite represents a residual slime of those insoluble impurities contained in various limestones which have been dissolved away. The whole region was involved in the crustal compression of the late Tertiary period, *i.e.* when the Alps were formed, and after the lavas of Antrim and Hesse had been extruded.

At Les Baux (Bouches-du-Rhone) the bauxite bed (30 feet thick) is interstratified between beds of limestone and pisolitic sandstones and clays of Lower Cretaceous age. The strata have been much disturbed by folding.

At Villevyrac (Hérault) the bauxite is found resting unconformably on a corroded surface of Upper Jurassic limestone, and is covered by beds of Upper Cretaceous age. The same is true for those of the Ariège and for the bauxites of the Var. In the occurrence at Le Pech de Foix (Ariège) the underlying Jurassic rock is a dolomite.

The quality and character of the bauxite in these different localities varies considerably, due to the amount and nature of the impurities, chiefly silica and ferric oxide, which are present in them. This variation could be expected if it is accepted that the bauxites are residual slimes (original insoluble impurities) of the various kinds of Jurassic dolomites and limestones which have been removed in solution. A study of the limestones in association with the bauxites of various localities may lead to the discovery of certain characteristic constituents which may possibly be detected both in the bauxite which remains and the limestone band from which it was derived.

In texture the bauxites are clay-like and impervious. The colour varies from chocolate to white—uniform and mottled. The material is generally soft, but locally hard and pisolitic. Much of it can be simply quarried. In the Var, however, it frequently has to be mined like an inclined bed of clay or coal. Sometimes the deposits are complicated or even duplicated by reason of the folding and faulting to which the enclosing strata have been subjected.



[*After Von F. Kerner-Marilaun.*

FIG. 1.

Sections of Bauxite Bed, near Brignolles, Var, France.

Unlike the American bauxites of the Appalachian area, which are, on equally slender evidence, also thought to be derived from limestones, the water-content of the French bauxites is remarkably low—10 to 14 per cent. as against 20 to 30 per cent. in the former. It is hardly possible that the differences between the Palæozoic dolomites of Georgia and the Jurassic dolomites and limestones of Ariège and Hérault are such that their residual products should be so different in degree of hydration. Differences in the composition of the limestones would explain differences in the composition of the bauxite. The French material is perhaps more ferruginous, and this matter might occur as ferric oxide and not as the hydrate. However, it is possible that an explanation of the lower water content in the bauxite of France may be found in the nature of the tectonic disturbance to which the containing strata were subjected. In Languedoc and Provence the evidence is wholly in favour of horizontal compressive forces which buckled the strata and squeezed the bauxite, whereas in the Appalachian area of Georgia, etc., it would appear that the earth's crust was subjected to tensional stresses. Pressure, therefore, may dehydrate a bauxite, but this has yet to be experimentally proved.

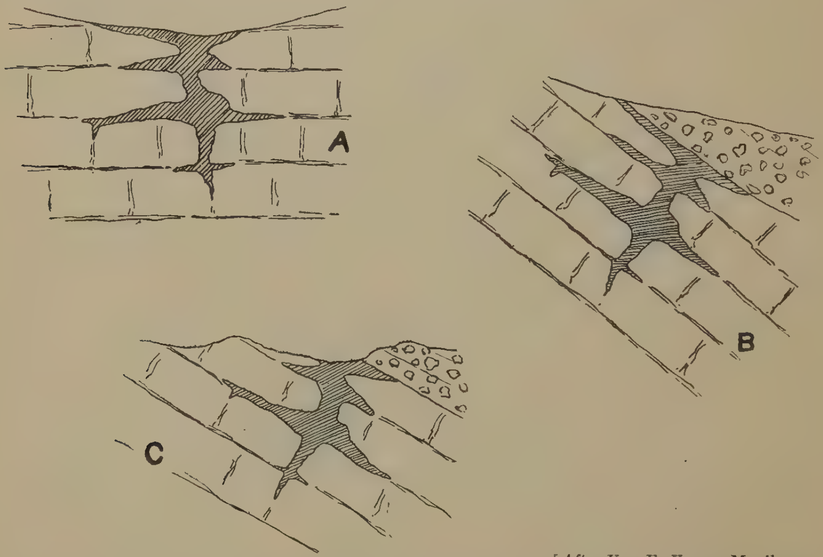
In the Puy-de-Dôme an apparently true detrital bauxite is found on the slopes of various basaltic plateaux—Apchat, between Saghat and St. Gervozy, near Marenges, and various other places. The bauxite is reported to rest on the denuded surface of gneiss, and to be covered by Miocene clays and basaltic lavas. (A. Lacroix, *Minéralogie de la France et de ses Colonies*, 3, Paris, 1901-1909.)

**Spain.**—The Rubio outcrop of bauxite in Catalonia (Barcelona) consists of pisolitic ore in nodular masses with clay. It occurs in gypsiferous marls and in limestone. The beds are unstratified, and the bauxite deposits appear to be best developed in the vicinity of faults. The formation of the bauxite is ascribed to hot springs from which the aluminium hydrate was deposited in early Eocene times. Both the silica and ferric iron percentages are high, so that the material is not attractive to producers of aluminium.

**Italy.**—The Italian bauxites of Lecce dei Marsi in Aquila (Abruzzo) and Pescosolido of the Bez Soro area in Terra di Lavoro (Liritale), and other tracts, are very similar in character and mode of occurrence to those of Provence and Languedoc in France. (C. Martelli, "Occurrence and Working of the Bauxites of Abruzzo, Italy," *Rassegna Mineraria*, 29, 1908; also B. Lotti, "Ostungarische und italienische Bauxit," *Zeits. f. Prakt. Geol.*, 16, 1908, p. 501.)

At Pescosolido, near Soro, in the Province of Terra di Lavoro, a bauxite bed occurs at an elevation of 2600 to 3000 feet on a spur of Monte de la Brecciosa. It lies unconformably on the eroded surface of a compact limestone, of which it contains numerous fragments. The bed is 17 to 26 feet thick, and is overlain by a white limestone into which it merges gradually. The strata have been tilted to an angle of 50° to the S.W.

The mineral is of the red ferruginous variety, and contains 54 to 58 per cent. alumina ; 18 to 31 per cent. ferric oxide ; 3 to 8 per cent. silica ; and, roughly, 11 to 14 per cent. water. (W. G. Rumbold, *Bauxite and Aluminium*, 1925, p. 81.) From the relationship between the bauxite and the upper (overlying) limestone it would appear that the bauxite may be newer, and formed at the expense of this bed. It is probable that evidence at the mine shows the upper limestone to have been contaminated with bauxite during formation.



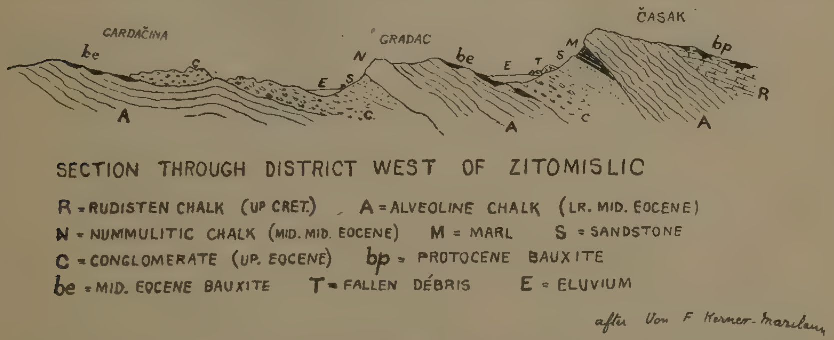
[*After Von F. Kerner-Marilaun.*

FIG. 2.—The sections A, B and C shown in Fig. 2 show, A, the deposition of bauxite in solution channels and pockets, and the obscure sections, B and C, indicate the results produced by folding and denudation after the bauxite was deposited.

In the Trieste district (Istria) the mode of bauxite occurrence is similar to that of France, but in Carniola there is a difference. Bauxite occurs in the vicinity of Lake Wocheiner and Feistritz in a dense earthy form, known as *wocheinite*. It is reported to lie in intimate association with strata of Jurassic and Triassic age, although an early Eocene to late Cretaceous period has been suggested as to the time of its formation. The peculiarity of the material is its particularly low, 8 to 9 per cent., water content. These bauxites have been elaborately discussed by Fritz Kerner-Marilaun. (See *Geologie der Bauxitlagerstätten des südlichen Teiles der österreichisch-ungarischen Monarchie*, Wien, 1916.) The accompanying sections A, B and C of Fig. 2 have been copied from this paper.

**Yugo-Slavia.**—Along the coastlands of the north Adriatic region in Dalmatia and, further inland, in Croatia, workable deposits of bauxite have been found. In the latter region the bauxite occurs both as surface cappings and in an interbedded position. It is found associated with limestones and dolomites, which are said to be of Triassic age. The material is frequently pisolitic and of a dull red colour. It may, as near Gracac, close to Vratce, rest on limestone and be overlaid by dolomite. Near Rudo Polje a bauxite deposit nearly 1000 yards wide has been traced for four miles. Bauxite, with an öolitic (pisolitic) structure and reddish-pink colour, occurs as a bed 3 feet thick interstratified with limestone at Dernis, in Dalmatia. There are numerous deposits of bauxite on several islands—Cherso, Veglia, etc., off the Dalmatian coast.

The bauxites of the East Adriatic region have received considerable attention from various writers—E. Katzer, Kispatic, F. Tucan, and others—but an excellent description of the mode of occurrence is given by Fritz Kerner-Marilaun (*Berg -und Hüttenmännisches Jahr.*, Band 69, u. 70, 1921-1922, Heft. 1.) The accompanying section through the district west of Zitomislić is of considerable interest (Fig. 3.)



SECTION THROUGH DISTRICT WEST OF ZITOMISLIC

R = RUDISTEN CHALK (UP CRET.) A = ALVEOLINE CHALK (LR. MID. EOCENE)
N = NUMMULITIC CHALK (MID. MID. EOCENE) M = MARL S = SANDSTONE
C = CONGLOMERATE (UP. EOCENE) bp = PROTOCENE BAUXITE
be = MID. EOCENE BAUXITE T = FALLEN DÉBRIS E = ELUVIUM

after Von F Kerner-Marilaun

FIG. 3.

N.B.—From the accompanying section across the district west of Zitomislic it is clear that there is no bauxite older than Upper Cretaceous (Kreide) age. It is difficult to discover how two different ages can be ascribed to the deposits. In detail the section shows evidence of intense over—or thrust-folding—to such an extent that an imbricated structure is obviously present. The Rudisten chalk has been over-thrust on to the Alveoline limestone of Casak, and these limestones have been pushed over the Eocene Marls (M). Similarly under Gradac the Alveoline limestone and Nummulitic beds are in reversed stratigraphical relationship owing to thrust faulting. (C. S. F.)

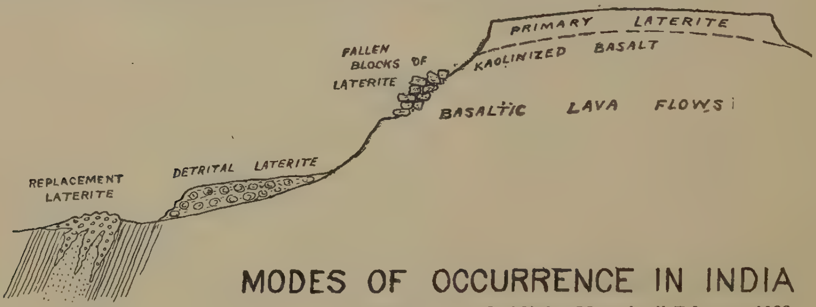
**Rumania (Hungary).**—Bauxite occurs in the Bihar Mountains associated with the plateau (malm) limestones (Upper Jurassic age). These limestones have been pierced by acid intrusions—granite, rhyolite, etc.—showing that the malm limestones have been greatly disturbed. They have been faulted and severely buckled. The bauxite, which is a red, pisolitic, semi-stratified rock, occurs very irregularly in pockets and holes in the surface of the limestone, or as accumulations of boulders. In some cases, *i.e.* Kiralyerdo plateau near Cucul, 40 feet of ore has been proved in a trial shaft.

Near Remecz a 12-feet bed of bauxite, with thin, marginal, siliceous layers, lies interstratified with the limestone. (W. G. Rumbold, *supra ;* and O. Pauls, "Aluminiumerze des Bihargebirges und ihre Ertstehung," *Zeits. f. Prakt. Geol.*, 21, 1923, pp. 521-572.)

## ASIA.

### India.

**The Deccan.**—The general manner of occurrence of Indian laterite is shown in Fig. 4. In nearly every case it has been found that the laterite represents the residual product of the prolonged atmospheric weathering of the flat-lying basaltic lavas of the Deccan. There are examples where the covering laterite has been derived from the weathering of granite, gneiss, shales, and clays, but these are rare. The volcanic period of the Deccan was rife during the Upper Cretaceous epoch, and appears to have terminated in the Peninsula with the close of the Mesozoic period. Since early Eocene times, therefore, the lava-covered tablelands have been exposed to sub-aerial weathering, some of the laterite being of Eocene age.



C. S. Fox.] [*Per favour : "The Mining Magazine," February,* 1922.

Fig. 4.

It has become increasingly clear in India during recent investigations that there is no genuine case in which primary laterite *has formed* below permanent ground water-level, and still less so in a lake.

Laterite is not found in process of formation in the Himalayan region, and not above an altitude of 5000 feet in the Peninsula. This last is a curious fact. Laterite occurs well-developed on Malcolm Peth (4710 feet), the plateau above Mahableshwar, but there is no laterite on Kalsubai peak (5396 feet), a little further to the north. Both hills, situated on the Western Ghats, are composed of basalt, and appear to be equally exposed to the south-west monsoon of Western India. Similarly, Girliguma hill (3757 feet) is capped with laterite, while Mahendragiri (4919 feet), some few miles to the east of it, has no laterite on its gneissose summit. The reason is probably due to the fact that plateaux of this altitude, over 4000 feet, seldom occur, and laterite cannot form on steep hillsides which slope up to peaks.

Recent observers in other countries have come to similar conclusions regarding the formation of laterite under water-level or on steep slopes. The experienced opinions of Woolnough in West Australia; Morrow-Campbell, Lacroix, and Kitson in West Africa; Harrison in British Guiana; and Leith and Mead in the United States are similar to those arrived at by geologists in India.

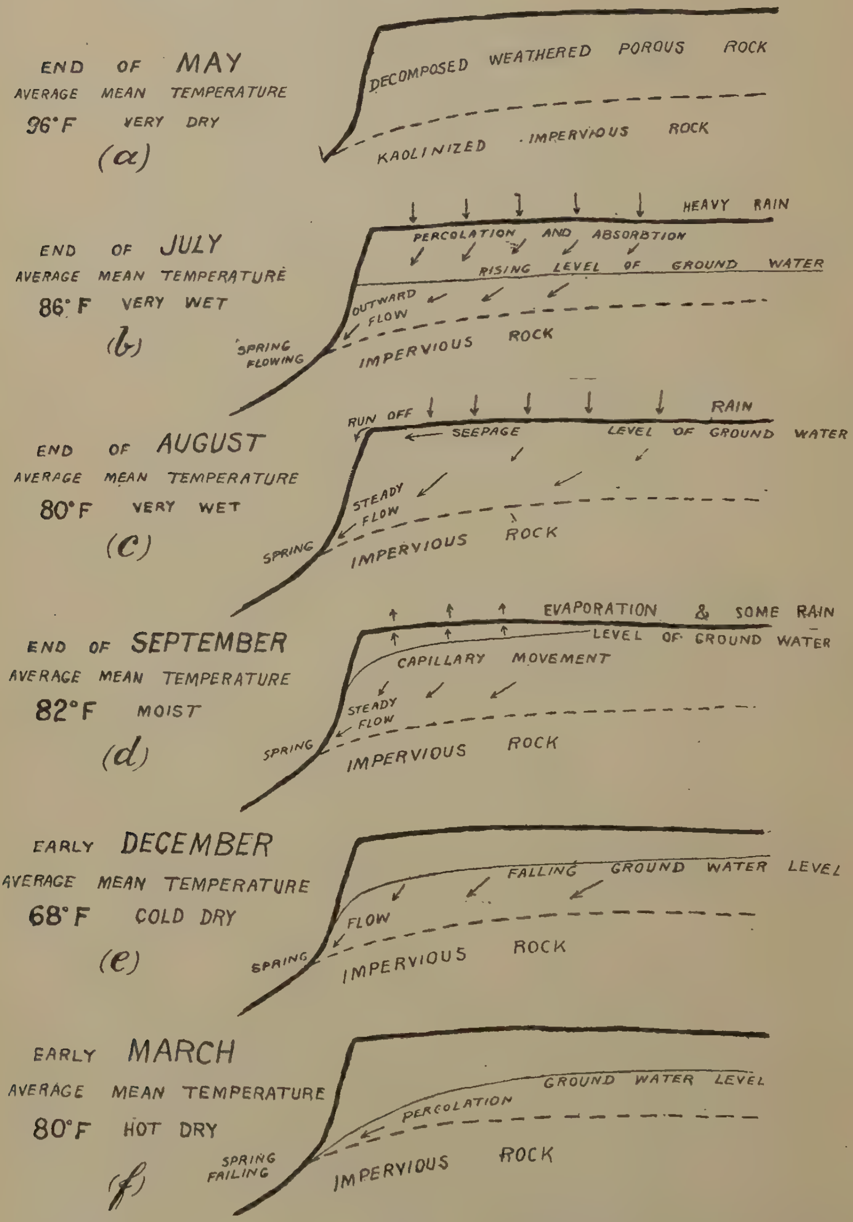
There seems to be a general agreement to-day that the conditions under which laterite may form, or lateritisation take place, are briefly as follows:—

1. The presence of a tropical or sub-tropical climate subject to dry and wet seasons or monsoons.
2. An elevated level or gently-sloping land surface not subject to appreciable erosion.
3. The exposed rocks to be of suitable chemical composition, *i.e.* contain alumina and ferric oxide in fairly appreciable percentages.
4. The rock to possess or develop a porous texture under the influence of weathering and allow rain-water to percolate into its mass.
5. The infiltrating water to remain for an appreciable period each year in the rock pores, but to eventually drain away.

The successive washings, drenchings, and dryings (depicted diagrammatically in the sections (*a*) to (*f*) in Fig. 5), to which the decomposed rock is subjected through countless years, must eventually remove all the more soluble constituents and leave behind the comparative insoluble aluminium and ferric hydroxides. The peculiar separation of the ferric hydroxide and hydrous silicate respectively to the top and bottom of a laterite mantle is thought to suggest powerful capillary action and the presence of electro-kinetic phenomena.

The south-west monsoon, which causes the wet seasons in India, is due to a moisture-laden current of air from the Indian Ocean to the hot land to the north, and could, therefore, not have been established until the break-up of the old Gondwana continent (or Lemuria). This regional subsidence appears to have been completed during the Mesozoic era—probably initiated in the Jurassic period, and finally submerged with the close of the Cretaceous volcanic activity. However, it is known that there is no *laterite* in India which is older than beds of Upper Cretaceous age, although there are laterites of all subsequent epochs, and laterite in process of formation to-day.

The accompanying sections, A to D in Fig. 6, show how during a vast period of time a laterite-capped plateau may, as a result of rapid erosion by lateral drainage, assume the detached position many such plateaux occupy on old water-sheds. (See Photograph I.)

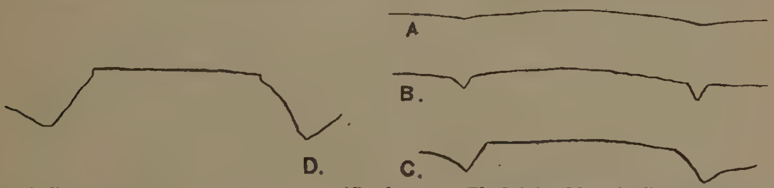


*C. S. Fox.*] [*Per favour: "The Mining Magazine," February*, 1922.

Fig. 5.—Circulation of Underground Water in Laterite Mantle.

The enormous lapse of time may be gauged when it is stated that many plateaux a few miles apart, of equal altitude and obviously recently separated, have between then valleys more than 2000 feet deep—carved out of horizontally bedded basaltic lavas!

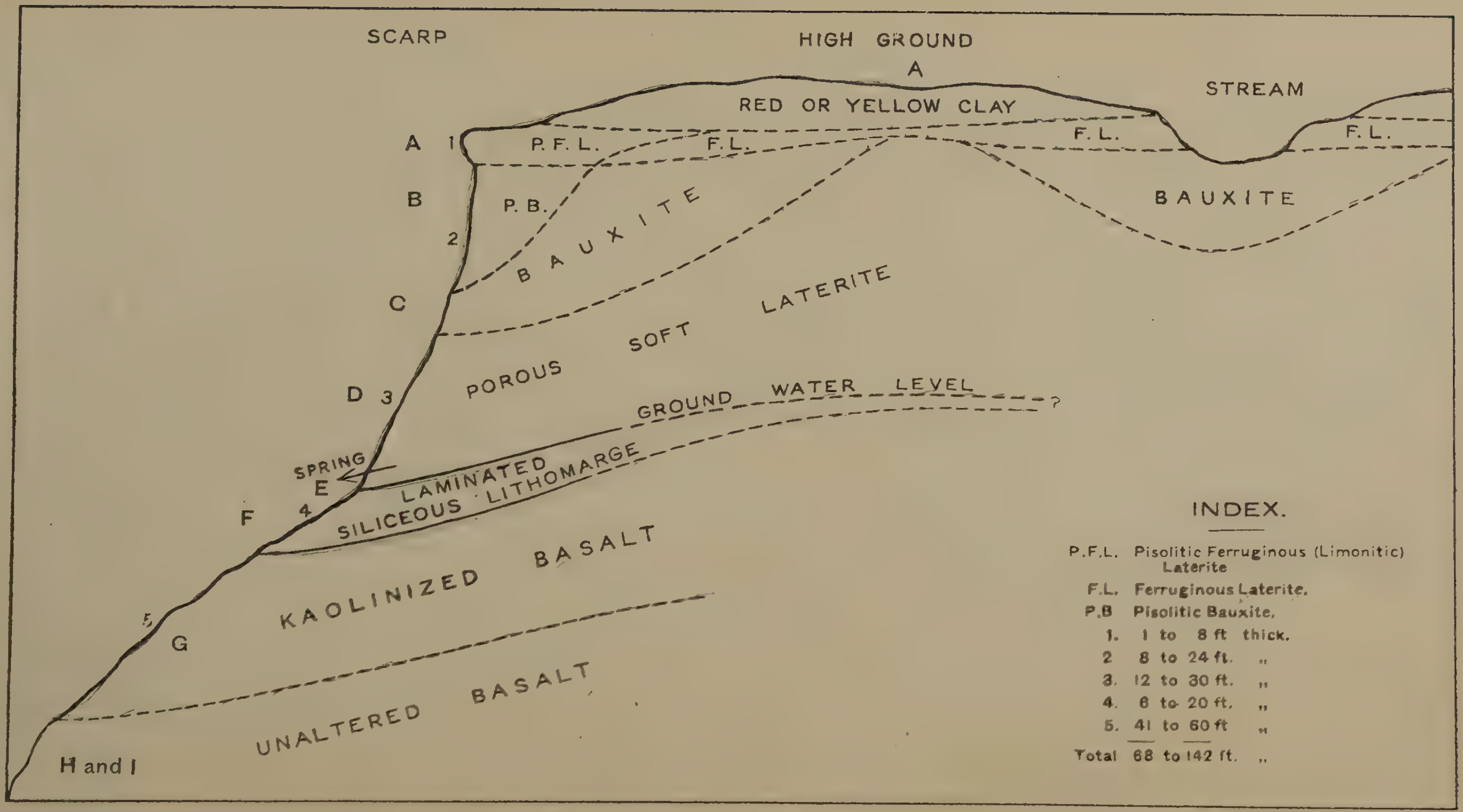
It has been found that bauxite only occurs in association with the oldest laterites, either as irregular lenticular masses in the primary laterite mantle itself, or as accumulations of boulders on the slopes or in the valleys below scarps of primary laterite. The detrital accumulations of bauxite are seldom found more than a few miles from their source of origin, and sometimes, as in the Rupjar valley of Balaghat, these agglomerated deposits may be richer than the laterite scarps from which they have been derived. In such cases a natural separation has obviously taken place; the softer ferruginous matter has dehydrated, broken up, and been washed away, leaving the tougher boulders of rich aluminous material (bauxite) behind. It has so far proved a waste of time to search for bauxite in those detrital laterites which occur far from regions where primary laterite has been formed. In India, therefore, it is most profitable to restrict one's prospecting to the oldest water-sheds of the Peninsula.



*C. S. Fox.*] [*Per favour:* "*The Mining Magazine,*" *February,* 1922.

Fig. 6.—The lines A, B, C, D, show stages in the development of an isolated plateau which has largely escaped surface erosion; thus the depth of porous decomposed rock on the oldest of such plateaux may be considerable.

A cliff of primary laterite is often found to be far from uniform in texture and composition. A uniform texture and structure in a mantle of laterite indicates newly formed material—as a rule, an unsatisfactory body to prospect for bauxite. The typical structure of an old laterite capping is shown in section in Fig. 7. The variation in composition and appearance is remarkable. The almost pure pisolitic limonite, yellow and red when fractured, covers, almost sharply, a bluish-grey or cream to pink coloured bauxite. The pisolitic mantle is seldom more than a few inches thick, but may be as much as 2 to 4 feet. It has been referred to by A. Lacroix as the *cuirasse de fer*. The underlying contrastingly coloured bauxite may be pisolitic, where exposed, but usually shows a vermicular texture further in the mass of the mantle. Inwards and downwards the enriched aluminous zone passes gradually into typical laterite, soft and vermicular with variegated colours, red and yellow and brown and cream. At the base there occurs the peculiar, complicated, laminated lithomarge, composed of white kaolin, with thin sheets of ferruginous clayey matter.



C. S. Fox.]

FIG. 7.—Diagrammatic Section of Part of Typical Laterite Plateau with Bauxite.

TABLE.—COMPOSITION OF MATERIAL AT VARIOUS SECTIONS AS FIG. 7.

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| $SiO_2$ . . . . | 3·20 | 0·66 | 3·66 | 2·36 | 64·85 | 41·88 | 37·31 | 47·44 | 47·34 |
| $TiO_2$ . . . . | 2.40 | 8·90 | 2·56 | 1·76 | ? | 7·76 | 3·33 | 1·71 | 1·87 |
| $Al_2O_3$ . . . . | 10·40 | 58·40 | 56·88 | 46·63 | 22·05 | 23·47 | 27·85 | 16·75 | 14·30 |
| $Fe_2O_3$ . . . . | 70·00 | 1·31 | 5·52 | 23·67 | 2·80 | 10·55 | 17·35 | 4·10 | 4·89 |
| FeO . . . . | — | — | — | — | — | — | — | 10·79 | 13·49 |
| CaO . . . . | — | — | — | — | 1·45 | — | — | 10·63 | 9·36 |
| MgO . . . . | — | — | 0·44 | 1·20 | 1·08 | 1·77 | 0·76 | 6·54 | 7·72 |
| Alkali . . . . | — | — | — | — | — | — | — | ? | ? |
| $H_2O$ dried at 105° C. | 14·00 | 31·54 | 30·12 | 24·49 | 5·12 | 14·75 | 13·40 | 2·20 | 1·32 |

A. Approximate analysis of pisolitic limonite cover (*cuirasse de fer*). B. Pisolitic grey to cream-coloured bauxite. C. Cream to pink bauxite. D. Normal laterite ($TiO_2$ sometimes high). E. White lithomarge (siliceous). F. Pink lithomarge (Panhala). G. Kaolinised basalt (deeply altered). H. Basalt (Sirguja). I. Basalt (Kolhapur).

There is another peculiarity attached to the location of bauxite masses in the laterites of Peninsular India. In the sketch plan, Fig. 8, several isolated plateaux are shown. They were originally parts of a single tableland. In accordance with my field experience, enrichments of bauxite are depicted at certain points. These, when carefully considered, prove to be situated under those channels of the surface drainage lines of an older plateau, which evidently existed in the earliest days of lateritisation. In some cases these channels are in existence to-day as stream courses, which discharge the run-off water through the re-entrant portions of the scarp line. In other cases the old drainage lines have been deflected or cut off by the active erosion of deep lateral valleys. It is, as a general rule, more economical in time to confine one's search to an examination of re-entrant scarps, and later, as experience is gained in piecing together the older physical geography, to investigate those positions where inference or deduction suggests the ancient drainage used to be. This can often be done by a careful study of a good topographical map. I tried an experiment of this kind in the Topla highlands of Balaghat—a tract I did not visit. I explained matters to the Deputy Commissioner of the district, and he sent instructions with samples of grey bauxitic and the yellow-red, *cuirasse de fer*, material, to the village people in the neighbourhood of the localities I decided might contain bauxite. The instructions were: (*a*) That the scarps, the upper 3 to 10 feet, in that vicinity should be searched; (2) that perhaps rich bauxite (sample) might be found in the beds of certain streams; (3) that the bauxite might be hidden by a thin mantle of the *cuirasse de fer* (sample); and (4) that the presence of white clay at the base of a scarp probably meant bauxite in the scarp above. In six out of the seven localities selected the bauxite samples were matched with bauxite that had been discovered locally.

From what has been said it is somewhat disconcerting to realise that in the majority of cases the bauxitic portion of a mantle of primary laterite is a very small part of the whole mass of laterite. It may happen that a little hillock may be entirely composed of grey pisolitic bauxite, but it is equally likely that practically no enrichment of bauxite occurs on a large plateau. It is impossible to warn prospectors sufficiently regarding an optimistic calculation of the amount of bauxite to be expected in a plateau of primary laterite.

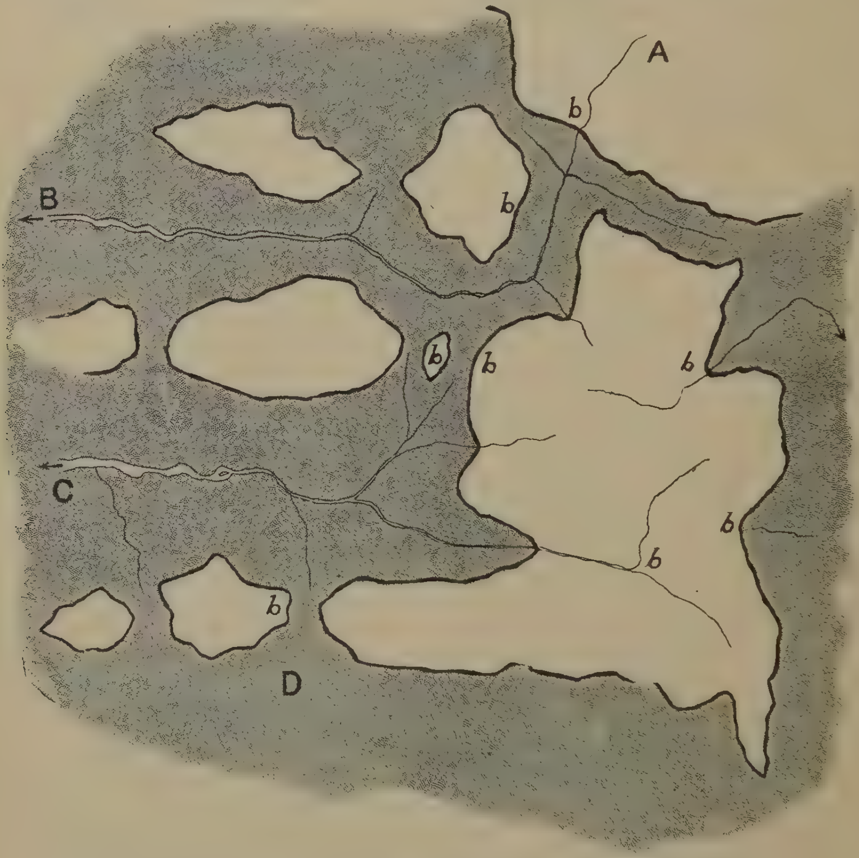


Fig. 8.—Sketch Plan of denuded Laterite Plateau showing Bauxite Segregations.

The composition of the material in various portions of a laterite-capped hill of basalt, as shown in Fig. 7, would be, taken in order vertically down the section, approximately as follows :—

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . . | 3·20 | 0·66 | 3·66 | 2·36 | 64·85 | 41·88 | 37·31 | 47·44 | 47·34 |
| $TiO_2$ . . | 2·40 | 8·90 | 2·56 | 1·76 | ? | 7·76 | 3·33 | 1·71 | 1·87 |
| $Al_2O_3$ . . | 10·40 | 58·40 | 56·88 | 46·63 | 22·05 | 23·47 | 27·85 | 16·75 | 14·30 |
| $Fe_2O_3$ . . | 70·00 | 1·31 | 5·52 | 23·67 | 2·80 | 10·55 | 17·35 | 4·10 | 4·89 |
| FeO . . | — | — | — | — | — | — | — | 10·79 | 13·49 |
| CaO . . | — | — | — | — | 1·45 | — | — | 10·63 | 9·36 |
| MgO . . | — | — | 0·44 | 1·20 | 1·08 | 1·77 | 0·76 | 6·54 | 7·72 |
| Alkali . . | — | — | — | — | — | — | — | ? | ? |
| $H_2O$ (dried at 105° C.) . | 14·00 | 31·54 | 30·12 | 24·49 | 5·12 | 14·75 | 13·40 | 2·20 | 1·23 |

1. Approximate analysis of pisolitic limonite.
2. Pisolitic grey to cream-coloured bauxite.
3. Cream to pink-coloured bauxite.
4. Normal laterite. $TiO_2$ sometimes higher.
5. Siliceous white lithomarge.
6. Pink lithomarge (Panhala).
7. Kaolinised basalt (deeply altered).
8. Basalt (Sirguja).
9. Basalt (Kolhapur).

It is to be understood that the above analyses do not refer to samples taken from a single cliff section. These results refer to various localities, but are put together here to give an idea of the kind of variation that occurs and can be expected in mining operations. Conclusions as to the variability in the percentages of the several constituents must therefore not be drawn in too fine a manner. The mode of occurrence, etc., of Indian laterites are discussed in detail in *Memoirs Geological Survey of India*, vol. xlix, pt. 1, 1923, and in the 2nd edition of the *Manual of the Geology of India* (1893).

**Surat and Jammu.**—Before closing the subject of the mode of occurrence of bauxite (lateritic) in India, mention must be made of the interbedded bauxite of Jammu (Kashmir) and stratified beds in Surat (Bombay Presidency). In both these cases the bauxite horizon is apparently overlaid, in a conformable manner, by sedimentary beds. This could be taken as evidence of a submergence of the bauxite, deposition of the sediment, and final elevation to its present position. If this interpretation was correct it will mean that quarrying operations will have to give place to mining once the outcrop is worked out and the bauxite followed down. The section in detail is shown on page 34.

In Surat the laterite is seen on both banks of the Kim River, and the outcrop extends northward to the Nerbada River and southward to the Tapti stream. The basal laterite is intimately associated with the top of westward dipping lava (basaltic) flows.

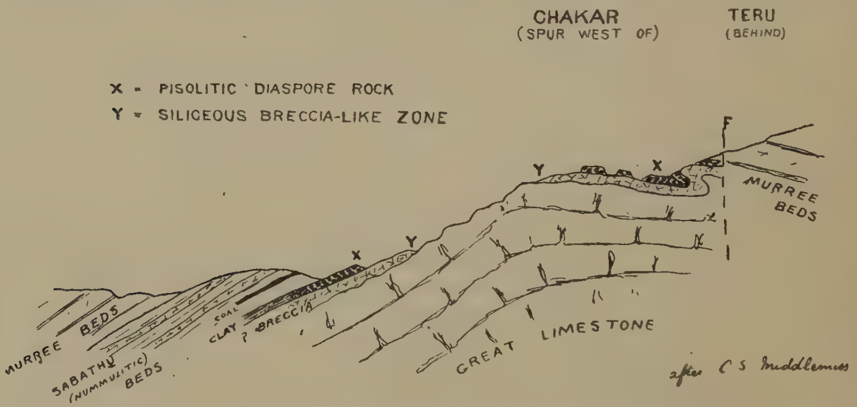
The evidence of such a section supports the opinion commonly held among Indian geologists that the Tertiary period was ushered in amidst great changes of land and sea in the Indian Ocean region.

Judging by the elevations at which primary laterite occurs in Western India, *e.g.* 4700 feet at Mahableshwar, 2700 feet at Matheran Hill, and barely 100 feet on Bombay Island, it is thought that a great system of step-faults occur by which the land has been dropped to the west into the Arabian Sea. The presence of these faults is suspected by the occurrence of hot springs along definite lines all the way down the coast from north of Bombay to Goa.

7. Agate gravel bed
6. Nummulitic limestone
5. Laterite (detrital)
4. Nummulitic limestone
3. Agate gravel beds
2. Laterite
1. Basaltic lavas

*N.B.*—The beds dip gently to the west, *i.e.* towards the Arabian Sea.

The section near Chakar in Jammu is yet more intriguing than that of Surat (Kim). In this Himalayan area the " bauxite horizon " of Jammu, which is said to be from 7 to 10 feet thick, overlies a siliceous breccia-like zone, and with it separates the underlying " Great limestone " (Jurassic ?) from the overlying Sabathu coal beds (Eocene) (Fig. 9). The associated strata have been greatly disturbed by folding and tectonic compression. The bauxites are siliceous, in fact, it is doubtful if the material below the top 4 feet can be called bauxite. The water content is low (10 to 14 per cent.), the specific gravity (up to 3·20) and hardness are suggestive of diaspore and the origin of the material is obscure. The horizon below the breccia-like zone certainly marks a " stratigraphical break " of some magnitude, while the overlying coal beds are suggestive of land conditions. The absence of dolerite or other aluminous rocks, and the presence of limestones below, are discordant factors in any theory of lateritisation. The aluminous horizon, with the siliceous material



after C S Middlemiss

FIG. 9.—Jammu Bauxite, section showing mode of occurrence of Bauxite (Diaspore Rock).

below, are said to be intimately related with the overlying strata, and consequently it cannot be the residual impurities of a massive limestone which has been removed in solution. My colleague Mr. D. N. Wadia tells me that the bauxite (diaspore) bed passes laterally into clay wherever overlying strata occur. It would thus appear to be a case of peculiar lateritic action on a bed of clay of peculiar physical character. A marked stratigraphical break at the same horizon occurs in the Simla region near Sabathu itself, where a peculiar siliceous pisolitic bed is to be seen. This wider aspect in judging the mode of origin of a deposit is frequently forgotten in the endeavour to advance a theory of origin which may account for local peculiarities. It is, therefore, possible that the horizon of the siliceous pisolitic diaspore-like substance has a regional significance, perhaps, in general, similar to that which gives a relationship to the bauxites of the North Mediterranean region.

# CHAPTER III.

## PHYSICAL CHARACTER OF BAUXITE.

All the evidence so far accumulated proves conclusively that bauxite is as much a rock as sandstone or clay or limestones are rocks. It is composed of simple constituents, but their condition and manner of existence with regard to each other is not clearly understood. Some definite amorphous compounds appear to exist. Since two or more of the hydroxides of (ferric) iron and aluminium are present, and can occur in variable amounts of each kind, it is evident that the specific gravity and hardness of the bauxite will vary accordingly. So also will the colour. Lateritic bauxites of primary (residual) origin have a minute cellular structure, whereas bauxites of the "terra-rosa" type are often as fine textured and impervious as clays, although pisolitic varieties of either may be indistinguishable from one another. It is evident that bauxites cannot have a definite melting temperature. The water of constitution in bauxites varies from less than 10 per cent. to over 30 per cent. If subjected to heat this combined water is driven off—usually in an irregular manner—there being large emissions of water at about 250° C., and again about 700° C. When the water has been entirely removed the bauxite is "dead burnt" or calcined. It is then in the anhydrous form known as emery—a mixture of the oxides of iron and aluminium and other contaminating substances. If the original bauxite was pure aluminium hydroxide the calcined product would be alumina—the equivalent of corundum. This substance has a fusion temperature of about 2000° C., a specific gravity of 3·9 to 4·1, and a hardness of about 9 of the Mohr scale. The presence of iron oxide reduces the fusion temperature, so that emery melts between 2000° C. to 1880° C., depending on the percentage of ferric oxide present. In the presence of other fluxing impurities, in appreciable amounts, the fusion may occur at a much lower temperature than 1880°.

The less water there is in bauxite the greater is its hardness and specific gravity. The massive lateritic bauxites are often used for building purposes in tropical countries, but the crushing strength of this material is low, and its resistance to abrasion is also weak. Both these properties could be greatly improved by partial calcination, and much augmented by complete calcination—if expense was no object.

The most characteristic features of most bauxites are their variegated colours (red, varying from pinkish-cream through chocolate to dark red) and their pisolitic porous textures. This is particularly true in the case of lateritic bauxites, but in the type provisionally regarded as the "terra-rosa" variety, the texture is generally finely granular and impervious, unless a pisolitic structure has developed. Exposed outcrops of lateritic bauxite generally have a very rough pitted surface. A scoriaceous aspect, suggestive of volcanic rock, may often occur. On gentle slopes or level ground the bauxite surface may be smooth, and the rock itself broken up into a kind of pavement. In the joints and cracks of this *pavé* small trees and shrubs often find sufficient soil for their existence. More normally the surface of a laterite plateau has a thin cover of red to yellow clay on which grass grows freely. In regions of heavy rainfall the lateritic bauxite may lie rough and bare, the surface of the rock being often black with a metallic glaze, thereby increasing its resemblance to a dark scoriaceous lava.

In scarps and cliff sections, where great masses have become detached, the material shows a vesicular to vermicular texture and presents a mottled appearance. The small cavities, fissures, and tortuous tubes in the rock are irregular, and generally have no obvious directional arrangement. Sometimes they are vertical, and occasionally horizontal. The mass of the material generally looks ferruginous, the tubes are often lined with a limonitic glaze, and where not previously weathered, filled with cream-coloured, powdery, aluminous laterite or gibbsite. The white substance filling the tubular cavities frequently occupies as great a volume of the mass as the surrounding matrix. The composition of the white infilling (A), and the red matrix (B), are as given below[1] :—

| | A | B |
|---|---|---|
| $SiO_2$ . . . | 3·66 | 2·36<br>(·09 free) |
| $TiO_2$ . . . | 2·56 | 1·76 |
| $Al_2O_3$ . . | 56·88 | 46·63 |
| $Fe_2O_3$ . . | 5·52 | 23·67 |
| MgO . . | ·44 | 1·20 |
| $H_2O$ (Comb.) . | 30·12 | 24·49 |

The colours are normally shades of red or dark reddish-brown to mottled red and white, streaked reddish-white, pink, mottled grey and greyish-white, and pink and greyish-white. In some scarps, or on the edges of steep slopes, a grey to pink or reddish-white pisolitic bauxite may be found in a hard massive deposit. In other cases, hummocks of friable pink to red and white, mottled, pisolitic bauxite may be exposed.

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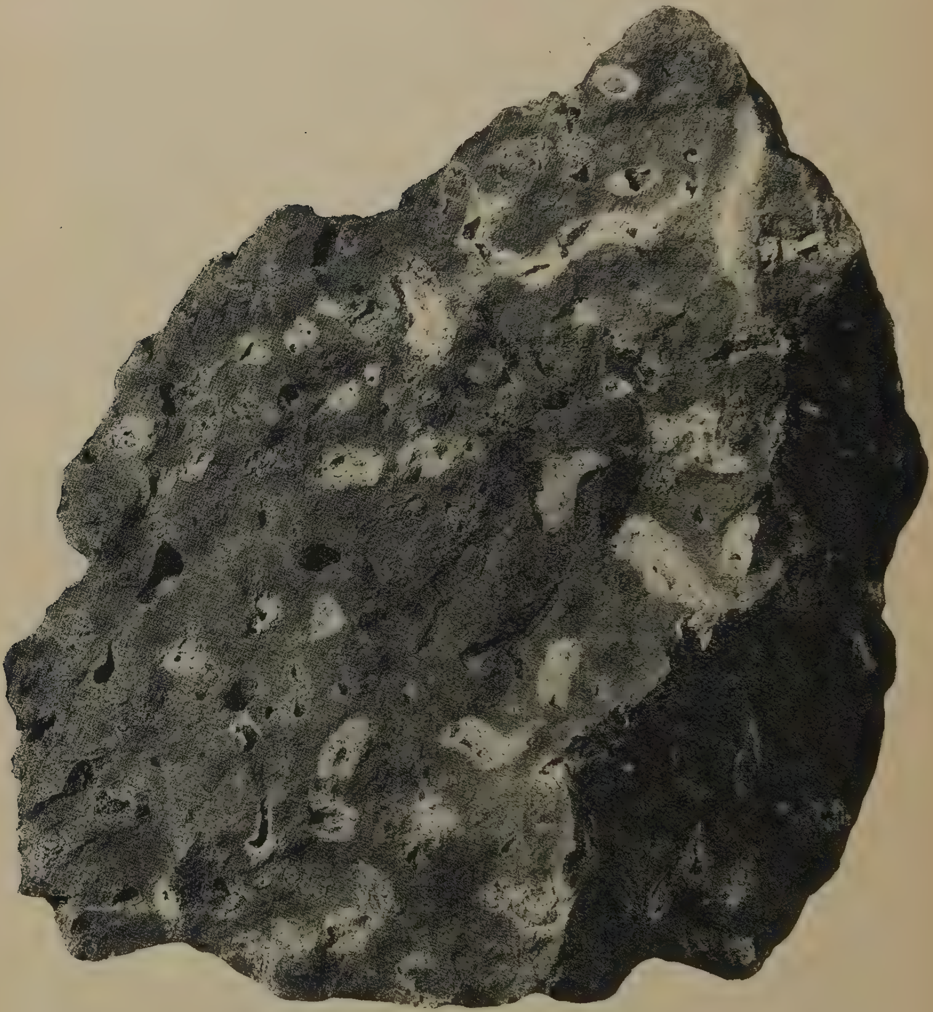
[1] Specimens collected by C. S. Fox near Harnai, Ratnagiri district, Bombay Presidency, India.

PHOTOGRAPH III.



*Photograph by K. F. Watkinson.*] [*G. S. I. Calcutta.*

Typical Laterite.

Showing the tubular or vermicular structure so common to laterites. ($\frac{3}{4}$ natural size.)

In certain rare cases layers, upwards of 3 to 4 feet in thickness, of loose pisolites, are found under a thin covering of soil in low, level ground (*e.g.* near Katni, Jabalpur district, India). It is equally common, as in British Guiana, to discover bauxite of a pale reddish-pink to pinkish-white colour, with no pisolitic texture, and no marked vermicular texture, but having the appearance of clay. On a closer scrutiny this is seen to have a sugary, granular texture. The pale-coloured Irish bauxite from Tuftarney could easily be mistaken for mottled white clays. Many of the red French bauxites are, so far as hand specimens go, indistinguishable from chocolate clays and shales. Thus it is seen that even the most experienced geologist may in certain cases be quite unable to say whether a given substance is a bauxite or not.

The most attractive colour-indications of good quality is that of a pale either pink, or reddish-white, or bluish-grey or greyish-white material, especially if it has a pisolitic texture—irrespective of it being soft and friable or relatively hard and compact. The specific gravity is no real guide—it may vary from 2·45 in some types to over 3·25 in others. Similarly, with regard to the hardness, the material may be soft and somewhat greasy, or it may be hard and tough. There is this to be said, however, that bauxite debris, when rolled down a slope or shaken in a pan, emits a peculiar rattle. But there is no test, short of a careful chemical analysis, which can be safely relied upon, even by an experienced observer, when one is confronted by an absolutely new discovery in an unfamiliar locality. A high combined water content is a good sign for a high alumina percentage. An observation by Dr. P. J. Brühl, that the water content multiplied by 2 equals the total amount of alumina, has proved to be a fairly satisfactory method of field assay in India. Much, however, depends on the judgment in choosing the sample.

An interesting series of analyses showing hardness and specific gravity, of selected pisolites of an oölitic bauxite from Arkansas, is given by D. C. Wysor (*Econ. Geol.*, vol. xi, 1916, pp. 42-50). He found a remarkable uniformity in the composition of the matrix of such oölitic bauxites.

| Sp. Gr. | H. | Composition of Pellets of Oölitic Bauxite. | | | | |
|---|---|---|---|---|---|---|
| | | $H_2O$. | $SiO_2$. | $TiO_2$. | $Fe_2O_3$. | $Al_2O_3$. |
| 3·01 | 6—7 | 14·58 | 2·20 | 1·70 | 9·00 | 72·52 |
| 2·93 | 5—7 | 17·66 | 1·54 | 2·00 | 10·70 | 68·10 |
| 2·77 | 5—6 | 19·62 | 2·52 | 2·20 | 11·50 | 64·16 |
| 2·69 | 4—6 | 20·42 | 3·32 | 2·00 | 9·80 | 64·44 |
| 2·55 | 4—5 | 26·02 | 3·48 | 2·40 | 7·40 | 60·70 |
| 2·53 | 4—5 | 27·54 | 3·76 | 2·70 | 5·70 | 59·30 |
| 2·43 | 4 | 29·82 | 2·16 | 2·20 | 6·50 | 59·32 |
| 2·42 | 2—4 | 31·96 | 2·08 | 3·40 | 2·70 | 59·86 |
| | General Composition of Matrix of Oölitic Bauxite. | | | | | |
| 2·38 | 2—3 | 31·0 | 1·56 | 4·20 | 5·30 | 57·14 |

*N.B.*—According to the above table, the matrix approximates to the composition gibbsite, and it is interesting to note that in Indian specimens crystalline gibbsite is best developed in the matrix of pisolitic bauxites.

It will be evident from the analyses given by Wysor, which includes a column of specific gravity determinations, that this method cannot possibly be of any use from a general assay point of view, however valuable it may prove in a detailed scientific investigation.

Certain determinations made by me (see *Mem. Geol. Surv. India*, vol. xlix, pt. 1; 1923, p. 18) are of interest in this connection :—

| Rock. | Moisture. Per cent. | Combined $H_2O$. Per cent. | Specific Gravity. | |
|---|---|---|---|---|
| | | | At first. | After 5 days Soaking in Water. |
| Pale, cream-coloured pisolitic bauxite | 1·52 | 23·8 | 2·496 | 2·508 |
| Pale pink pisolitic bauxite . . | 0·64 | 27·76 | 2·533 | 2·545 |
| Reddish-pink pisolitic bauxite . . | 1·00 | 22·92 | 2·598 | 2·624 |
| Yellowish-red, limonitic, pisolitic laterite . . . . . . . | 0·78 | 15·58 | 2·872 | 2·897 |
| Dark red, hematitic, pisolitic laterite [1] | 0·60 | 18·52 | 3·021 | 3·064 |

Pisolitic structures evidently are developed only near the surface, or in zones of infiltrating seepage water. These pisolites generally have a concentric structure. The core, however, may be of earthy, grey, clayey matter, or it may be dark and ferruginous. It may consist of nests of crystalline gibbsite, or it may contain a number of smaller pisolites. Occasionally, however, in stream beds, nodules apparently of grey pisolitic laterite are found, which, when broken open, are seen to consist of dark hematitic laterite with a coating of aluminous matter. It is consequently necessary, as a rule, to expose a fresh surface of laterite before pronouncing an opinion on its character.

The microscopic aspects of thin sections of some pisolitic bauxites from the Jabalpur district are shown in the Photo-micrographs (see I and II). The amorphous character of the oölitic pellets and the crystalline nature of the matrix are well seen.

Thin sections of laterite and bauxite can be prepared in the ordinary way with Canada balsam, but care must be taken that in the process of fixing to glass slides the section is not heated beyond a temperature of 150° C. Even this temperature should not be maintained for long. If the rock slip be subjected to a temperature

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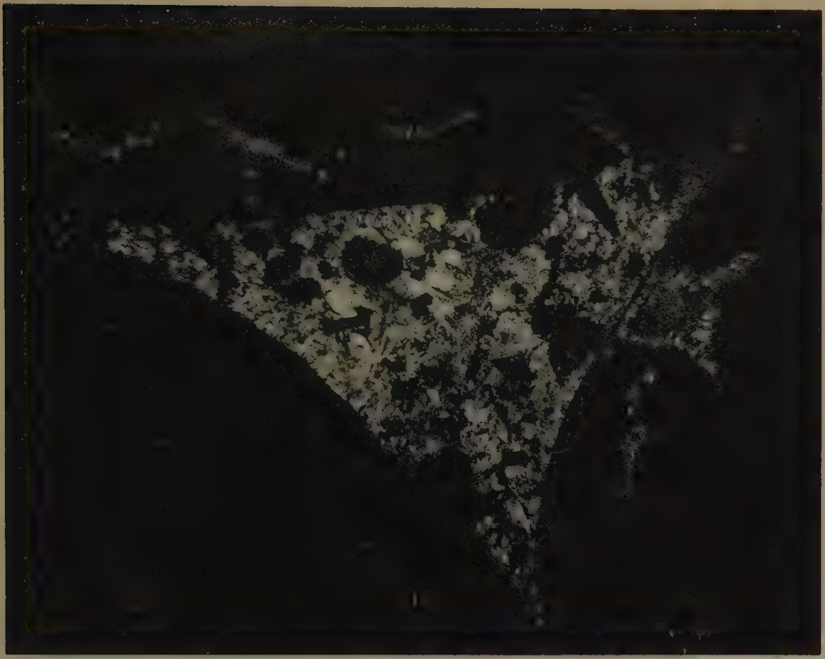
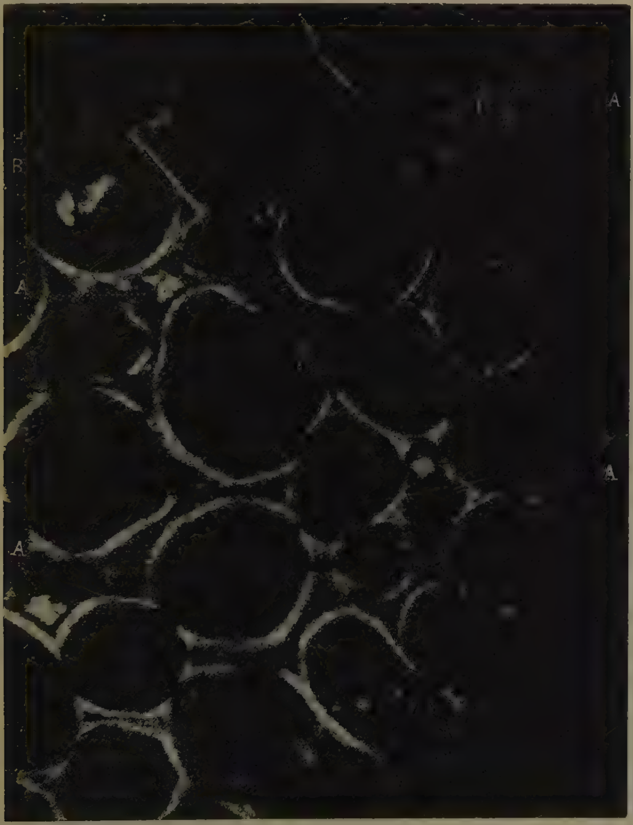
[1] This specimen contained much crystalline gibbsite in the matrix between the amorphous pisolites. It had evidently undergone considerable dehydration (gelatination of the colloids).



1.—Laterite.

Dark red pisolitic (hematitic) laterite showing crystalline structure of the matrix (gibbsite), and slight development of gibbsitic veins in the hematitic pisolites. Crossed nicols, natural light.



*C. S. Fox, Photo-micro.*] 2.—Bauxite. [*G. S. I. Calcutta.*

Ferruginous pisolitic bauxite showing crystalline coating of pisolites and crystalline development: (*a*) in matrix, and (*b*) in some pisolites. Crossed nicols, natural light. × 50.

of 260° C., the crystalline components will be destroyed, and probably no trace of the crystalline structure will be seen when the section is examined under the microscope.

The microstructure of the amorphous parts of a thin section of laterite is exceedingly complicated. W. W. Taylor, speaking of the structure of *gels*, says that they have a cellular microstructure, honeycombed, reticulated, radiate and dendritic, etc., but that all these are of secondary formation in *gels* obtained from emulsoids by evaporation. The only original structure of these precipitates is the fine-grained crystalline structure.

A microscopic examination has revealed crystalline gibbsite in many thin sections of Indian bauxite and laterite, as seen above. The mineral was commoner in the pisolitic varieties of both the bauxitic and ferruginous types, and was consistently present in the matrices of the pisolitic laterites. Many of the pisolites were veined with nests and patches of crystalline gibbsite. No other recognisable mineral was detected. The same negative results as regards the presence of other possible minerals, *e.g.* diaspore, etc., with the possible exception of xanthosiderite (by Morrow Campbell), has attended the investigations of other observers when working with American and European bauxites. It should be mentioned that these investigations have been made with thin sections under the microscope in both transmitted and reflected light. It was thought that perhaps some of the following minerals might be detected in reflected light :—

| | | | | |
|---|---|---|---|---|
| Hematite | Hexagonal | $Fe_2O_3$ | 100 | Fe = 70<br>O = 30 |
| Turgite | Orthorhombic | $2Fe_2O_3, H_2O$ | $Fe_2O_3$ = 94·7<br>$H_2O$ = 5·3 | Fe = 66·3<br>O = 28·4 |
| Göthite | ,, | $Fe_2O_3, H_2O$ | $Fe_2O_3$ = 89·9<br>$H_2O$ = 10·1 | Fe = 62·9<br>O = 27·0 |
| Limonite | Monoclinic | $2Fe_2O_3, 3H_2O$ | $Fe_2O_3$ = 85·0<br>$H_2O$ = 14·5 | Fe = 59·8<br>O = 25·7 |
| Xanthosiderite | ,, | $Fe_2O_3, 2H_2O$ | $Fe_2O_3$ = 81·6<br>$H_2O$ = 18·4 | Fe = 57·1<br>O = 24·5 |
| Limnite | ,, | $Fe_2O_3, 3H_2O$ | $Fe_2O_3$ = 74·7<br>$H_2O$ = 25·3 | Fe = 52·3<br>O = 22·4 |

But the investigation was in general disappointing. No single mineral except hematite has been determined with certainty, and the hematite only occurs in obviously dehydrated laterite.

A similar effort was made with regard to the corresponding aluminous series, *i.e.* :—

| | | | | |
|---|---|---|---|---|
| Corundum | Hexagonal | $Al_2O_3$ | —— | Al = 52·9<br>O = 47·1 |
| ? | Orthorhombic | $2Al_2O_3, H_2O$ | $Al_2O_3$ = 91·9<br>$H_2O$ = 8·1 | Al = 48·9<br>O = 43·0 |
| Diaspore | ” | $Al_2O_3, H_2O$ | $Al_2O_3$ = 85·0<br>$H_2O$ = 15·0 | Al = 44·96<br>O = 40·04 |
| Wocheinite | Monoclinic | $2Al_2O_3, 3H_2O$ | $Al_2O_3$ = 79·45<br>$H_2O$ = 20·55 | Al = 42·03<br>O = 37·42 |
| ? | ” | $Al_2O_3, 2H_2O$ | $Al_2O_3$ = 73·9<br>$H_2O$ = 26·1 | Al = 39·09<br>O = 34·81 |
| Gibbsite | ” | $Al_2O_3, 3H_3O$ | $Al_2O_3$ = 65·4<br>$H_2O$ = 34·6 | Al = 34·6<br>O = 30·8 |

It is interesting to note that F. Laur (*Trans. Amer. Inst. Min. Eng.*, vol. xxiv, 1895, p. 234) had attempted to explain the variation in the composition of different bauxites by suggesting that there was a family of definite bauxite minerals, and that normal bauxite comprised a mixture of different amounts of these bauxite minerals. He constructed an empirical formula as follows :—

Bauxite = A + Pe + C, in which
A = alumina from 66 to 68 per cent.,
Pe = $H_2O$, $Fe_2O_3$, and $SiO_2$, 28 per cent., and
C = the oxides of titanium, manganese; chromium, and vanadium, 4 per cent.

He then grouped his bauxites into a family of minerals according as—

Pe might be one-third each of $H_2O$, $Fe_2O_3$, and $SiO_2$,
or one-half each of $H_2O$ and $SiO_2$,
or one-half each of $H_2O$ and $Fe_2O_3$,
or wholly $H_2O$.

There is little doubt that with suitable calculations it is possible to represent the analyses of any bauxite as being made up of a mixture of certain definite compounds, but there is no evidence to show that these compounds exist as minerals, and this method of speculation is misleading.

To put the matter to the test, and to avoid possible errors, by the destruction of minerals in the preparation of microscope slides, I carried out the following experiment. A carefully chosen specimen of a slightly pisolitic, compact, grey bauxite (with pink, white, and reddish-yellow patches), from Netarhat (B. and O., India), having the following composition :—

| | |
|---|---|
| $Si_2O$ | 1·01 per cent. |
| $TiO_2$ | 8·12 ” ” |
| $Al_2O_3$ | 59·32 ” ” |
| $Fe_2O_3$ | 6·34 ” ” |
| CaO | Trace. |
| MgO | 1·21 ” ” |
| Loss by ignition (chiefly $H_2O$, but some $CO_2$) | 25·91 ” ” |

(The specific gravity was 2·457 to 2·476 after six hours soaking in water.)

was crushed, sorted between 40- and 60-mesh sieves, and separated in mixtures of tetra-bromide and toluol (having specific gravities of 2·33, 2·51, 2·69, and 2·97), with the results given below :—

| | |
|---|---|
| All fragments sank in liquid of | 2·33 specific gravity. |
| 25 per cent. remained suspended or afloat in liquid of | 2·51 „ „ |
| 38 per cent. floated in liquid of | 2·69 „ „ |
| 25 per cent. floated in liquid of | 2·91 „ „ |
| and remainder 12 per cent. sank in this liquid. | |

The four separations were then examined under the microscope. No dissimilarity was observed in the grains except that there were a greater number of specks of ilmenite (?) *attached* to the heavier particles. Some grains were coated red or yellow with ferric oxide, but the substance of the particles was gibbsite—free of attached specks in the first separation, and more and more loaded in the others. No trace of any other definite substance was noticed, and there was certainly no diaspore. A bauxite that might prove to contain diaspore is that which occurs in Jammu (Kashmir). This material is very much harder than normal Indian bauxite, and is of a dense grey appearance, with a specific gravity above 3·25. Its composition, allowing for the siliceous admixture, is suggestive of the formula $Al_2O_3 . H_2O$, as seen from the accompanying analyses A and B. The sample C is a cream-coloured bauxite from the St. Pargoire tunnel, near Villeveyrac, in Hérault (France) :—

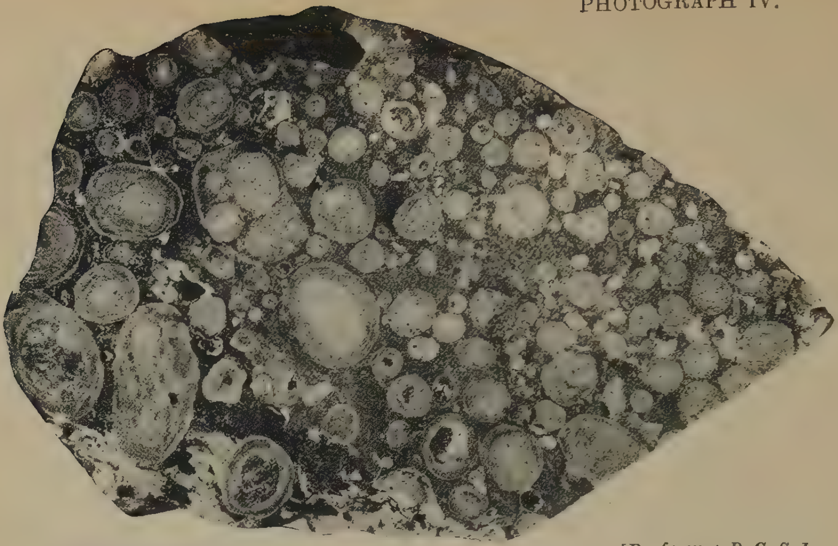
| — | A | B | C | Diaspore. |
|---|---|---|---|---|
| $SiO_2$ . . | 12·85 | 14·40 | 2·00 | —— |
| $TiO_2$ . . | 3·38 | 2·45 | ? | —— |
| $Al_2O_3$ . . | 69·90 | 67·20 | 82·00 | 85·00 |
| $Fe_2O_3$ . . | 1·08 | 0·80 | 0·10 | —— |
| $H_2O$ . . | 10·90 | 13·15 | 14·20 | 15·00 |
| Undetermined . | ? | ? | 1·70 | —— |

A common property of some lateritic bauxites, which are soft when first dug out, is their tendency to harden on exposure to air. This is a well-known characteristic of common Indian laterite, and advantage is taken of it, both in quarrying and dressing the stone if it is to be used for building purposes. The same phenomenon does not appear to be associated with the "terra-rosa" type of bauxite. It is thought that the explanation is to be found in the greater water-content of the laterite type, and that the hardening is due to partial dehydration. The bauxite (lateritic type), which shows this property, is invariably the freshly quarried rock and not material which had previously been exposed to the dry atmosphere. The hardening process is gradual, and may take several weeks of dry weather to become evident.

Another peculiarity of lateritic bauxite is its capacity for reconsolidation. Debris from a laterite scarp which accumulates on the slopes or in the valley below frequently becomes cemented into a solid mass, resembling the original material in the scarp. This power for agglomeration is evidently stronger in highly aluminous laterites (bauxite) than in the ferruginous varieties. As a result, any lateritic debris, exposed to the wash of the rains and the scorching heat of the sun, will be subjected to a natural concentration process, whereby the ferruginous matter will be separated from the highly aluminous material. The bauxite will become agglomerated closer to the source from which the lateritic debris was derived. An instructive example of this mode of concentration is to be found in the valley about Rupjar, Balaghat district (C.P., India). The most reasonable explanation for this phenomenon is that it results from the precipitation of some cementing material—a different cement for the aluminous laterite to the one which cements the ferruginous laterite. It can be said with certainty that the cements are aluminium hydroxide and ferric hydroxide respectively. Each of these cementing compounds is in solution in the seepage water, and both are deposited therefrom. The former substance is evidently less soluble, and consequently precipitates more rapidly than the ferric hydroxide. This entails a selective, differential deposition of these—the aluminium hydroxide earlier on the bauxite fragments and the ferric hydroxide later on the ferruginous debris. The precipitation of limonitic matter is a common feature in association with seepage waters from lateritic areas. To the presence of this ferric hydroxide, in solution, is ascribed the formation of pisolitic limonite of the *cuirasse de fer* (see Fig. 7, also Photographs II, III, and IV). The evidence for the presence of soluble aluminium hydroxide in similar waters is not always easy to procure. However, in the dry weather, it is not uncommon to find in the beds of some streams (in laterite regions) grey nodules of apparently rich bauxite. These pseudo-pebbles, if broken, frequently show dark red (ferruginous) laterite with a coating of a luminous matter—presumably aluminium hydrate (certainly not silica or kaolinite). Traced to fundamental considerations, the action possibly is dependent on the greater rapidity with which the *gel* of ferric hydroxide solates and the tardiness with which the *sol* of this compound gelatinates when compared with the similar reversibility of the colloid form of aluminium hydroxide.

It may not be out of place here to refer to these so-called " pebbles " or " pseudo-pebbles " of bauxite, because they may occur in quantity and thus suggest to an observer the detrital origin of bauxites generally. From what has been said above, it is evident that such nodules have not travelled far from the rock from which they have been derived. Furthermore, they are not pebbles in the

PHOTOGRAPH IV.

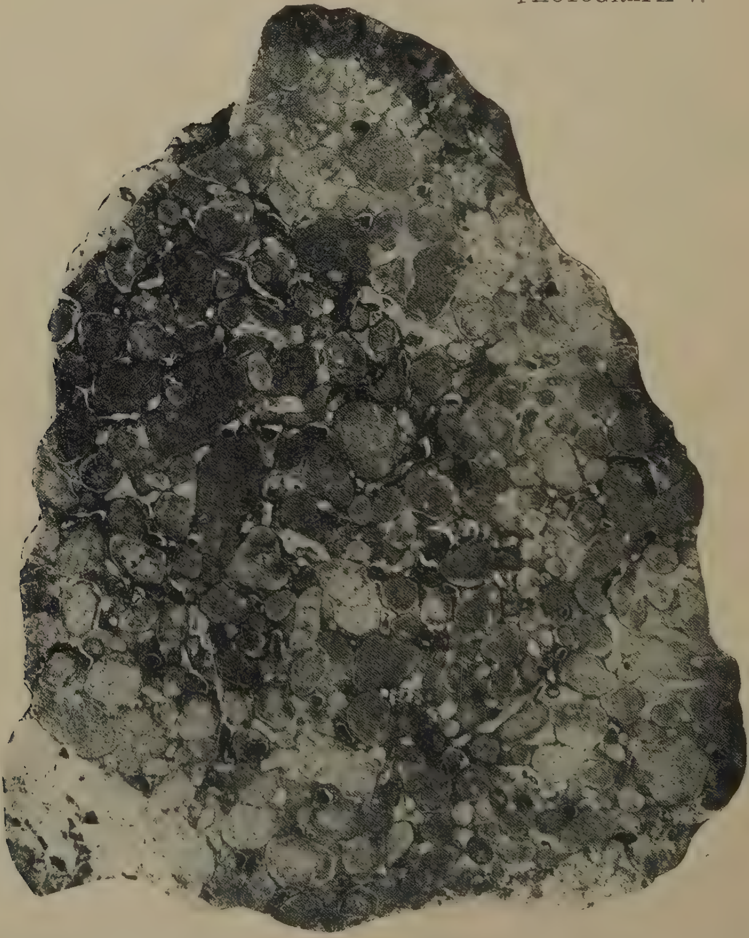


*Photograph by K. Watkinson.*] [*Per favour: D. G. S. I.*

Grey Pisolitic Bauxite or Aluminous Laterite.

Showing the variable size and structure of the pisolites. Highly polished surface. ($\frac{3}{4}$ natural size.)

PHOTOGRAPH V.



*Photograph by K. Watkinson.*] [*Per favour: D. G. S. I.*

Showing structure of the accretionary pisolite limonite, known as *cuirasse de fer*, which overlies grey bauxite in many Indian occurrences. Polished surface. (Natural size.)

sense in which we speak of water-worn pebbles. They are rarely water-worn.

> "An examination of the internal structure of these pebbles (see Plate) is usually sufficient to disprove their sedimentary origin. Many have *grown* by an accretionary process, although it is as difficult to account for their peculiar form as it is to explain clearly the concentric pisolitic structure which many of them have. They may be caused by the deposition of a colloidal film and a gradual growth into a spheroidal form—some concentric, others oölitic, and others quite irregular. This phenomenon is, however, peculiar to the superficial portion of a deposit and, in a way, is partly detrital. However, they have not been moved far from their place of formation, and certainly have not been deposited in stream courses. The question is not one to be laboured, as true pebbles of bauxite are of course found." (*Mem. Geol. Surv. India*, vol. xlix, pt. 1, 1923, pp. 37-38.)

Many detrital bauxites (laterites) show clearly the conglomeratic, as distinct from pisolitic, structure suggestive of their mode of origin. In contrast with this it is usual to find primary bauxite with a more massive, brecciated appearance. However, it is often quite impossible to say from hand specimens which are which. In the field, if the occurrences are not complicated by tectonic folding and dislocation of the strata, it is generally quite a simple matter to decide whether a given bauxite is of primary origin or re-deposited detrital material. It is sometimes possible to detect replacement occurrences. In the type areas of the Deccan of India the most remarkable features are the contrasting materials in juxtaposition (see Fig. 7)—pisolitic limonite resting on grey pisolitic bauxite, and this passing into vermicular reddish laterite, which in turn lies on peculiarly laminated lithomarge, and under this is seen kaolinised basalt.

# CHAPTER IV.

## CHEMICAL COMPOSITION OF BAUXITE.

If we scrutinise the various analyses of (lateritic) bauxite and (terra-rosa) bauxite, which are given in Chapter I, page 8, and other places in this book, and compile particulars, it will be found that the various constituents are :—

(1) Aluminium hydroxide, the essential component, possibly in two colloidal forms and as crystalline gibbsite.

(2) Ferric hydroxide—the commonest impurity and also probably present in two colloid forms, and perhaps a crystalline form as xanthosiderite.

(3) Ferric oxide—is recognisable as hematite in certain dehydrated laterites, and is thought to be present in the terra-rosa type of bauxites. Ferrous hydrate and oxide have never been found present in bauxite.

(4) Silica—as quartz is a frequent insoluble impurity, but it is probably more frequently present in small percentages as hydrous alumino silicate, and perhaps rarely as secondary colloidal silica.

(5) Titanium—either as the dioxide or hydrated oxide, is a conspicuous impurity in lateritic bauxites which have been formed from basaltic rocks.

(6) Manganese—as psilomelane and pyrolusite, has been found in ferruginous laterites, but is not a common constituent in rich bauxite.

(7) Lime—generally as carbonate, possibly as bicarbonate, is frequently present in very small amounts, and so also is

(8) Magnesia—which is more common than lime. Both these constituents may occur in abnormal quantities in the terra-rosa type of bauxite.

(9) Potash and soda are rare constituents in bauxite, but detectable in traces in some argillaceous varieties of laterite.

(10) Chromium and vanadium have been detected in the lateritic bauxites of some localities ; so also has zirconium (zircon).

(11) Sulphur and phosphorus are often present in bauxites of the lateritic types.

(12) Gold, tinstone, copper, diamonds, nickel, cobalt, and other elements and metallic oxides, often in payable quantities, have been found in laterite under special conditions.

The list could possibly be further enlarged by including rare elements and complex substances. In fact, when it is remembered that bauxite is considered to be the insoluble residue of various alumina-carrying rocks—*e.g.* granites, syenites, diorites, basalts, clays, shales, schists, gneisses, etc.—the wonder is that there are not a larger number of component substances present in laterite.

The proportion of alumina in a bauxite gives some indication of the degree of lateritisation, and the greater the percentage of combined silica the smaller has been the action of lateritisation. The whole question of composition depends on the process of bauxite formation and on the constituents in the original rock which has suffered lateritisation. In detrital and certain replacement laterites (so far as I know, there are no definitely proved workable occurrences of replacement bauxite) there are obviously many impurities, which either have been introduced or could not be assimilated at the time of development.

The composition of the original rock from which laterite has resulted can often be traced in the constituents in the laterite. In India the laterite over certain basalts is highly titaniferous, and it is known that the basalts contain appreciable amounts of titania. In Cuba a ferruginous laterite formed from a serpentinised peridotite contains detectable amounts of nickel and cobalt. In the Gold Coast some of the bauxites contain gold, due to the lateritisation of rocks carrying stringers of gold-bearing quartz. Tinstone is found in certain laterites in Nigeria, etc.

Knowing that no rock, unless it contains the lateritic constituents, alumina and ferric, can be lateritised, it is evident that quartzites, sandstones, limestones, and dolomite cannot suffer lateritisation. If they contain felspathic constituents and other aluminous or ferruginous minerals, an impure variety of laterite may result from the former, arenaceous rocks, and terra-rosa may result from the latter, calcareous rocks. If the lateritic constituents are brought to sandstones, and occasionally to limestones, it is conceivable that a replacement laterite may be formed. Such cases (see Fig. 4) are, however, exceedingly unusual, and until a chemical analysis of the original rock is made, it is not certain whether the necessary constituents were not already present.

It is interesting to examine the composition of the possible rocks from which laterite may, if the texture of the altered rock is suitably porous, be formed. Such a list is given below :—

| *Igneous Rocks.* | Average Percentage of | | | Percentage of Silica. |
|---|---|---|---|---|
| | $Al_2O_3$. | $Fe_2O_3$. | Total Lateritic Constituents. | |
| 1. Granite family | 17 | 3 | 20 | 65 to 75 |
| 2. Trachyte—Syenite | 20 | 4 | 24 | 55 to 66 |
| 3. Andesite—Diorite | 18 | 6 | 24 | 50 to 65 |
| 4. Nepheline—Phonolite | 23 | 3 | 26 | 40 to 60 |
| 5. Anorthosite | 25 | 1 | 26 | 60 |
| 6. Basalt—Dolerite | 17 | 8 | 25 | 48 to 54 |
| 7. Augitite—Limburgite | 14 | 14 | 28 | 44 |
| 8. Peridotite | 5 | 10 | 15 | 30 to 48 |
| *Sedimentary Rocks.* | | | | |
| 1. Aluminous shale | 40 | 3 | 43 | 43 |
| 2. Brick clay | 30 | 7 | 37 | 45 |
| 3. Potters' clay | 24 | 2 | 26 | 60 (18 p.c. free). |
| 4. Fire clay | 31 | 1 | 32 | 50 (12 p.c. free). |
| 5. Residual clay | 12 to 33 | 6 to 1 | 18 to 34 | 30 to 70 |
| 6. Kaolinite | 39 | — | 39 | 46 |
| *Metamorphic Rocks.* | | | | |
| 1. Phyllite | 23 | 7 | 30 | 60 |
| 2. Slate | 23 | 2 | 25 | 55 |
| 3. Mica schist | 24 | 6 | 30 | 55 |
| 4. Basic gneiss | 18 | 10 | 28 | 50 |
| 5. Syenitic gneiss | 20 | 4 | 24 | 65 |
| 6. Granitoid gneiss | 20 | 2 | 22 | 70 |

(*Mem. Geol. Surv. India*, vol. xlix, pt. 1, 1923, p. 35.)

From the above analyses it is evident that syenite, phonolite and anorthosite are highest in alumina among the igneous rocks. Aluminous shale, and in fact almost all clays, contain more alumina than the igneous rocks, but they have, as a rule, an impervious texture. Among the metamorphic rocks the clay-slates, etc., are highest in alumina, and generally intermediate, in this respect, between the igneous and sedimentary argillaceous rocks.

The accompanying analyses, both of the residual material—laterite, either bauxite or iron ore—and of the original rock, are of considerable interest. I have chosen only a few of the more valuable analyses, but several equally reliable results are also available. It has, however, not been possible to discover detailed analyses of shales and mica schists in genetic relationship with overlying laterite. Nor have I considered it necessary to repeat the figures for the bauxite from the basalts of the Vogelsberg, as given in Chapter V, Part I.

In the examples given, it is assumed that the alteration of the rock has been effected by lateritisation, as described in Chapter V, page 72. The rocks—serpentine from Cuba; hornblende schist, etc., from British Guiana; nepheline syenite from Arkansas, U.S.A.; dolerite and nephelene syenite from West Africa; basalts from Ireland and India; and gneissose rocks from India—all show high alumina and ferric and ferrous percentages, and were, therefore, originally rich in lateritic constituents. In detail they are as follows:

## CUBA.

**Laterite from Serpentine (Serpentinised Peridotite).**—A few of the analyses are given below:—

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 2·58 | 2·38 | 1·42 | 2·44 | 3·66 | 39·80 |
| $Al_2O_3$ | 15·71 | 20·81 | 14·23 | 6·91 | 6·51 | 1·39 |
| $Fe_2O_3$ | 66·20 | 64·70 | 68·70 | 72·40 | 69·20 | 10·14 |
| MgO | — | — | — | — | Trace. | 33·69 |
| $H_2O$ | 10·20 | 10·63 | 9·5 | 12·35 | 12·73 | 13·31 |
| Fe | 46·37 | 45·34 | 48·09 | 50·63 | 48·42 | 7·10 |
| Cr | ·92 | ·96 | 1·04 | 2·08 | 2·43 | ·20 |
| Ni and Co | ·38 | ·33 | ·36 | 1·21 | 1·34 | ·97 |
| P | ·016 | ·022 | ·019 | ·005 | ·005 | ·001 |
| S | ·12 | ·12 | ·16 | ·16 | ·06 | ·06 |

1. At surface of deposit.
2. 2 ft. from surface.
3. 4 ,, ,,
4. 9 ,, ,,
5. 19 ,, ,,
6. 29 ,, ,, (the serpentine rock).

(*Mem. Geol. Surv. India*, vol. xlix, pt. 1, 1923, p. 193.)

The specimens were collected by Messrs. Leith and Mead in their examination of the iron ores (ferruginous laterite) about Nipe Bay in the Mayari and Moa districts of the Oriente Province.

## BRITISH GUIANA.

**Bauxite from Hornblendic Rocks.**—The following analyses by Harrison are of great interest:—

| | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| | a | b | a | b | a | b | a | b |
| $SiO_2$ (free) | 4·30 | 13·77 | 1·60 | 11·98 | ·03 | 7·73 | — | ·30 |
| $SiO_2$ | 45·45 | 1·67 | 49·59 | 3·82 | 51·06 | 4·80 | 49·06 | 2·83 |
| $Al_2O_2$ | 12·18 | 32·47 | 15·80 | 30·94 | 15·70 | 40·33 | 18·87 | 56·42 |
| $TiO_2$ | 4·60 | 4·37 | ·40 | 1·70 | 1·70 | 4·32 | ·88 | 0·83 |
| $Fe_2O_3$ | ·03 | 25·14 | 3·08 | 28·21 | 1·68 | 18·28 | 1·89 | 11·59 |
| FeO | 9·88 | 1·60 | 11·20 | 3·28 | 8·57 | 3·84 | 4·51 | — |
| CaO | 11·79 | ·01 | 9·58 | ·02 | 9·11 | ·10 | 11·79 | ·01 |
| MgO | 9·54 | ·09 | 5·63 | ·08 | 7·74 | ·27 | 10·95 | ·20 |
| MnO | ·48 | ·06 | — | — | ·41 | — | ·34 | — |
| $Na_2O$ | 1·19 | — | 2·09 | ·06 | 2·38 | ·54 | ·97 | ·13 |
| $K_2O$ | ·11 | ·16 | ·60 | ·07 | 1·55 | ·24 | ·06 | ·10 |
| $H_2O$ | ·35 | 20·52 | ·30 | 19·93 | ·35 | 19·90 | ·43 | 27·84 |
| $P_2O_5$ | ·06 | ·002 | ·008 | ·001 | ·01 | ·01 | Trace. | Trace. |

1 {a. Hornblende schist, b. Aluminous laterite} Yarikita, Amacura River.
2 {a. Diabase, b. Aluminous laterite} Tumatumari Potaro River.
3 {a. Diabase, b. Aluminous laterite} Kumaru, Demerara River.
4 {a. Epidiorite, b. Aluminous laterite} Issorora, Aruka River.

(*Mem. Geol. Surv. India*, vol. xlix, pt. 1, 1923, p. 196.)

The above specimens were collected by Sir John Harrison, so that both the sampling and analyses have been carried out by one man. The results must be considered as the best obtainable.

## United States of America.

Specimens from quarry in Arkansas State. The unaltered syenite is a nepheline bearing rock, and therefore similar to that collected by Lacroix in West Africa.

**Bauxite from Nepheline Syenite.**—The following analyses by Mead and Leith show the passage from the unaltered syenite to bauxite :—

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ | 58·00 | 52·64 | 39·80 | 10·64 |
| $TiO_2$ | ·40 | 1·20 | 3·30 | 1·20 |
| $Al_2O_3$ | 27·10 | 29·56 | 37·74 | 57·46 |
| $Fe_2O_3$ | 1·86 | 1·06 | 1·60 | 2·5 |
| FeO | 3·30 | ·80 | ·10 | ·20 |
| CaO | 1·65 | — | — | — |
| MgO | ·25 | — | — | — |
| $Na_2O$ | 6·70 | 4·46 | — | — |
| $K_2O$ | ·25 | ·44 | — | — |
| $H_2O$ (moisture) | 1·22 | — | — | — |
| $H_2O$ (combined) | — | 9·00 | 17·00 | ·28 |

1. Unaltered syenite. 2. Altered syenite. 3. Kaolinised syenite. 4. Bauxite.

(*Mem. Geol. Surv. India*, vol. xlix, pt. 1, 1923, p. 191.)

### WEST AFRICA.

The specimens were collected by Prof. A. Lacroix, who travelled from the coast in the Futah Jallon area inland to the Niger River and then back to the Ivory Coast.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . . | 51·27 | 5·83 | 1·30 | 9·91 | 35·14 | 2·80 | 2·21 | 6·97 | 14·55 | 6·07 | ·37 | 56·88 |
| $TiO_2$ . . | ·70 | 1·29 | 1·03 | 1·44 | ·70 | — | ·12 | 1·02 | ·9 | ·66 | ·90 | ·29 |
| $Al_2O_3$ . . | 12·36 | 37·03 | 60·19 | 22·41 | 40·08 | 8·7 | 55·83 | 50·62 | 46·31 | 39·79 | 57·12 | 22·60 |
| $Fe_2O_3$ . . | 3·29 | 31·73 | 3·91 | 52·53 | 4·12 | 77·2 | 5·22 | 17·69 | 17·65 | 32·26 | 7·41 | ·97 |
| FeO . . | 6·16 | — | — | — | — | — | — | — | — | — | — | 2·19 |
| CaO . . | 10·66 | ·19 | ·17 | Trace. | ·45 | — | ·24 | ·17 | ·19 | ·17 | ·17 | 1·33 |
| MgO . . | 13·26 | ·06 | — | ·43 | ·21 | — | ·19 | — | — | — | — | ·56 |
| $Na_2O$ . . | 1·60 | — | — | — | — | — | ·49 | — | — | — | ·26 | 8·30 |
| $K_2O$ . . | ·41 | — | — | — | — | — | ·27 | — | — | — | ·37 | 5·57 |
| $H_2O$ . . | ·40 | 23·02 | 32·0 | 13·26 | 17·84 | 11·4 | 30·47 | 25·80 | 21·40 | 21·05 | 33·71 | ·98 |
| $P_2O_5$ . . | ·11 | — | — | — | — | — | — | — | — | — | — | ·08 |
| Miscellaneous . | — | ·96 | 1·40 | — | 1·46 | — | 5·74 | — | — | — | ·30 | ·26 |

1. Unaltered diabase (dolerite), Bongourou Mountain.
2. Laterite immediately above diabase.
3. Bauxite on surface overlying 2.
4. Alluvial laterite from Tinkisso.
5. Fotabar.
6. Laterite analysed by P. Berthier from the Futah Jallon territory. He noted a trace of chromium.
7. Roume (Zone du depart).
8. Siguiri pisolitic bauxite ; this contains 6·23 per cent. free $SiO_2$.
9. From Fotaya ; contains 13·33 per cent. free $SiO_2$.
10. Surface cuirass of ferruginous laterite.
11. Compact bauxite from Kassa.
12. Unaltered nepheline syenite, Kassa ; this contains ·26 per cent. of chlorine.

All the analyses are by M. Boiteau ; they are given by Lacroix in his paper on the laterite of Guinea. (*Mem. Geol. Surv. India.*, vol. xlix, pt. 1, 1923, p. 201.)

## IRELAND.

**Bauxite from Basalt.**—

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ . . | 6·01 | 7·95 | 4·0 | 3·50 | 13·0 |
| $TiO_2$ . . | — | — | 2·0 | 2·0 | 6·0 |
| $Al_2O_3$ . . | 61·89 | 48·12 | 35·5 | 35·0 | 42·0 |
| $Fe_2O_3$ . . | 1·96 | 2·36 | 45·50 | 38·0 | 2·0 |
| CaO . . | — | — | ·35 | — | — |
| $H_2O$ . . | 27·8 | 40·33 | 12·65 | 21·5 | 37·0 |

1. Bauxite from Glenrave. (Richards.)
2. ,, ,, Irish Hill. ,,
(The $H_2O$ is very high, and probably includes a large percentage of moisture.)
3. Ferruginous laterite from Tully. (Cameron.)
4. ,, ,, Co. Antrim. (Siemens.)
5. ,, ,, ,, ,, (Imperial Institute.) In this there is 16 per cent. of moisture.

The laterite almost certainly resulted from the weathering of the underlying trap, the composition of which is given below :—

| | 1 | 2 |
|---|---|---|
| $SiO_2$ . . . . | 39·72 | 53·70 |
| $Al_2O_3$ . . . . | 14·32 | 25·41 |
| $Fe_2O_3$ . . . . | 27·87 | 8·95 |
| CaO . . . . | 4·15 | 4·55 |
| MgO . . . . | 4·00 | — |
| Alkalies and moisture. | 9·94 | 4·30 |

1. Basalt from Slieve Gallion. (Apjohn.)
2. Basalt from Antrim. (Hodges.)

(*Mem. Geol. Surv. India*, vol. xlix, pt. 1, 1923, p. 214.)

## INDIA.

Specimens collected and analysed by the Geological Survey of India. The analyses are taken from Dr. C. S. Fox's report on "The Bauxite and Aluminous Occurrences of India" (*Mem. Geol. Surv. India*, vol. xlix, pt. 1, 1923, p. 26).

**Bauxite from Basalt.**—

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| $SiO_2$ . . | 47·34 | 47·44 | 47·00 | 1·44 | 1·66 | 2·76 |
| $TiO_2$ . . | 1·87 | 1·71 | 1·44 | 6·32 | 8·90 | 9·52 |
| $Al_2O_3$ . . | 14·30 | 16·75 | 13·53 | 62·32 | 56·40 | 57·03 |
| $Fe_2O_3$ . . | 4·89 | 4·10 | 2·05 | 2·65 | 7·10 | 3·94 |
| FeO . . | 13·49 | 10·79 | 16·76 | — | — | — |
| MgO . . | 7·72 | 6·54 | 6·87 | ·38 | ·39 | 1·20 |
| CaO . . | 9·36 | 10·63 | 9·55 | Trace. | — | — |
| Alkalies . . | ? | ? | ? | ·28 | — | — |
| $H_2O$ . . | 1·23 | 2·20 | 1·36 | 26·70 | 25·36 | 25·80 |

A. Basalt from Kolhapur, Kolhapur State.
B. „ „ Main Pat, Sirguja.
C. „ „ West of Sandnigag Waterfall, Ranchi District.
D. Bauxite „ Panhala, Kolhapur State.
E. „ „ Main Pat, Sirguja.
F. „ „ West of Sandnigag Waterfall, Ranchi District.

**Bauxite from Para-Gneiss (Khondalite) and from Granitoid Gneiss (Charnockite).**—

| | G | H | I | J |
|---|---|---|---|---|
| $SiO_3$ . . | ·93 | 74·17 | 3·75 | 75·54 |
| $TiO_2$ . . | 1·04 | — | ·37 | — |
| $Al_2O_3$ . . | 67·88 | 17·16 | 47·36 | 13·75 |
| $Fe_2O_3$ . . | 4·09 | 7·82 | 23·37 | 4·99 |
| FeO . . | — | — | — | — |
| MgO . . | — | ·69 | — | ·69 |
| CaO . . | ·36 | ·61 | — | ·94 |
| $Na_2O$ . . | — | ·83 | — | 1·55 |
| $K_2O$ . . | — | — | — | 3·34 |
| $H_2O$ . . | 26·47 | ·11 | 24·47 | ·28 |

G. Bauxite from Korlapat Hill, Kalahandi State.
H. Khondalite, Kalahandi State.
I. Bauxite, Hill Tracts, Madras Presidency.
J. Acid Charnockite.

A considerable amount of experimental work has been done by H. M. Arsandaux (*C.R. Ac. Sci.*, vol. cxlviii, 1909, pp. 936-938, 1115-1118, " Sur la composition de la bauxite "). He says, speaking of the alumina, silica, etc., in bauxite :—

> The state in which these substances occur is well nigh impossible to determine by optical examination or analysis of bauxite as it consists of quite isotropic substances, which are, further, by their state of extremely fine division, not mechanically separable. . . . In a fairly large number of French bauxites poor in $SiO_2$ and $TiO_2$, I have been able to show that the degree of hydration of the alumina is almost fixed and consequently independent of the proportions of $Fe_2O_2$ in the specimens.

Continuing, he says :—

> The interpretation of these results leads to the following conclusions, applying to all the analysed specimens except one :—
>
> (*a*) $Al_2O_3$ exists in bauxite in a state of hydration approximately that of the definite hydrate $Al_2O_3 . H_2O$ (*i.e.* $Al_2O_3 = 85$ per cent., $H_2O = 15$ per cent.). This is independent of the iron contents of these ores, even in different portions of the same specimens.
>
> (*b*) The oxide of iron is approximately anhydrous. This is supported by the low value of the losses on heating to 250° C. (precipitated hydrate of iron loses about 95 per cent. of its water of hydration by heating at 250° C. for several hours), also by the fact that bauxites are red, red-brown, red-violet, and do not show ochreous hues.
>
> (*c*) The oxide of titanium, generally in too low proportion for its condition to be judged quantitatively, is probably in the form of meta-titanic acid. Indeed, it is readily soluble in sulphuric acid, but insoluble in hydrochloric acid, and the water content of meta-titanic acid (18·4 per cent.), is not incompatible with that of the insoluble residue on treating with HCl.
>
> (*d*) The $SiO_2$, which may be separated by treatment with $H_2SO_4$, which is dissolved only in an insignificant proportion by prolonged boiling of the ores with 20 per cent. $Na_2CO_3$, is doubtless in an amorphous hydrated aluminium compound.

In the second half of the above paper, Arsandaux suggests that the French bauxite consists of mixtures of $Al_2O_3 . H_2O$, $TiH_2O_3$, and $Al_2H_4Si_2O_9$, containing respectively 15 per cent., 18·4 per cent., and 13·9 per cent. of combined $H_2O$. He does not think that any of the silica exists as a free hydrate.

The method generally adopted for showing the results of a quantitative chemical examination, as tabulated in the analyses just discussed, unfortunately does not give a clue to the actual compounds present. In the majority of cases they are not simple oxides. Hydroxides appear to be prevalent in the laterites, but in most other cases the constituents are usually in a state of combination with each other.

**Alumina.**—For some purposes, particularly in the case of bauxite, which is to be purified to alumina or utilised in the preparation of aluminium salts, it is important to know much more about the condition in which the alumina occurs than is given in an ordinary chemical analysis. We want to know if the alumina is present as a hydroxide or in other combination, also whether it occurs in an amorphous or crystalline form.

The results of heating bauxite gradually to higher and higher temperatures, and noticing the evolution of the water of combination, has led to the belief that the alumina must be present in at least three forms—crystalline gibbsite and two colloidal hydroxides. Crystalline gibbsite is a common constituent in the matrix of pisolitic bauxites, as has frequently been observed under microscopic examination (see Photo-micrographs, p. 41).

Much of the alumina is, however, present as colloidal hydroxide, and in some cases an appreciable percentage appears to be held in combination, possibly with the silica which is present, or in certain types with the titania, but of this latter combination we have no clear evidence.

G. D'Achiardi (*Pro. verb. Soc. Toscana Sci. Nat. Pisa*, vol. xiii, 1903, pp. 93-96) refers to the remarkable property of certain Pescina (Italy) bauxites in being easily and energetically attacked by sulphuric acid. He has also indicated that the titania determinations are invariably too low, owing to the solubility of part of the titania.

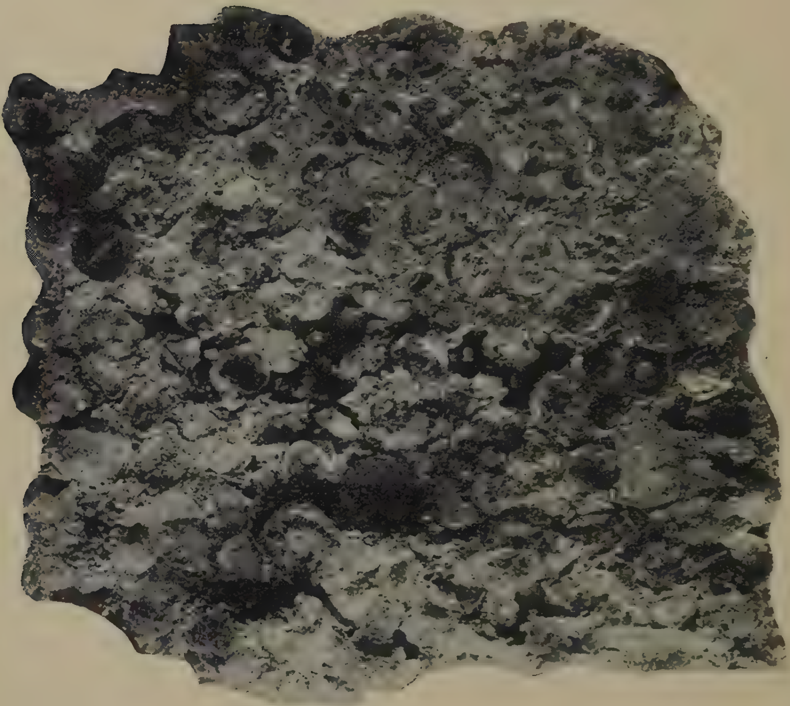
W. F. B. Berger (*Eng. Min. Jour.*, vol. lxxvii, 1904, pp. 606-607), when discussing the bauxites of Georgia and Arkansas, pointed out that although the French bauxites contain over 70 per cent. alumina as against only 60 per cent. in the best alum quality bauxite of Georgia, this total alumina, in an analysis, was misleading. When both these types of bauxite are subjected to the customary 50° B. sulphuric acid attack in alum-making, the French material will yield only 50 to 55 per cent. alumina, whereas the bauxite from Georgia was capable of yielding 57 per cent. alumina. The opinion advanced in explanation of this is that some of the impurities in the French ore are chemically combined with part of the alumina, whereas in the American ore the chief impurity, silica (as quartz ?), is a physical diluent.

It is interesting to notice the manner in which H. M. Arsandaux presents certain analyses (by M. Blot) of bauxite from Les Baux (Bouches-du-Rhône, Provence) :—

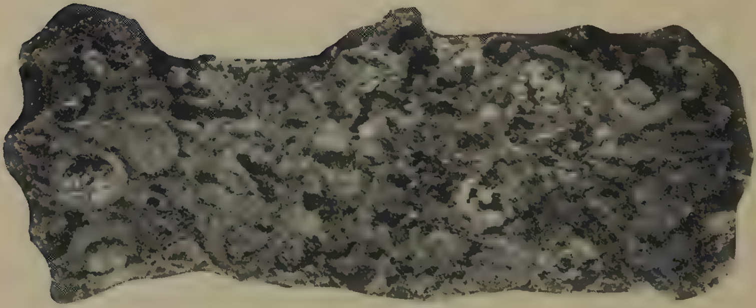
| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ . . . . . | 8·7 | 2·3 | 25·4 | 28·4 |
| $TiO_2$ . . . . . | 3·4 | 1·6 | 1·3 | 2·4 |
| $Al_2O_3$ (soluble in HCl) . . | 1·1 | 15·3 | 1·2 | 1·0 |
| $Al_2O_3$ . . . . . | 68·8 | 45·8 | 35·1 | 52·7 |
| $Fe_2O_3$ . . . . . | 8·4 | 12·2 | 25·3 | ·3 |
| $H_2O$ at 960° C. . . . | 14·1 | 20·7 | 11·2 | 14·3 |
| $H_2O$ at 600° C. . . . | 11·4 | 15·6 | 10·0 | 12·3 |
| $H_2O$ at 250° C. . . . | ·3 | 6·7 | ·5 | ·4 |
| $H_2O$ (in matter soluble in HCl) | ·2 | 5·9 | ·99 | 1·05 |

This question of **available alumina** has an important commercial aspect which was noticed by W. B. Phillips and H. Hancock (*Jour. Amer. Chem. Soc.*, vol. xx, 1898, pp. 209-225) over a quarter of a century ago. These writers showed that the question of solubility of alumina might be very seriously affected by calcination of the bauxite prior to shipment. Their data require further determination, in order to fix the exact temperatures involved.

PHOTOGRAPH VI.



A.—Hard Pink Pisolitic Bauxite (India).



B.—Hard Grey Pisolitic Bauxite (India).

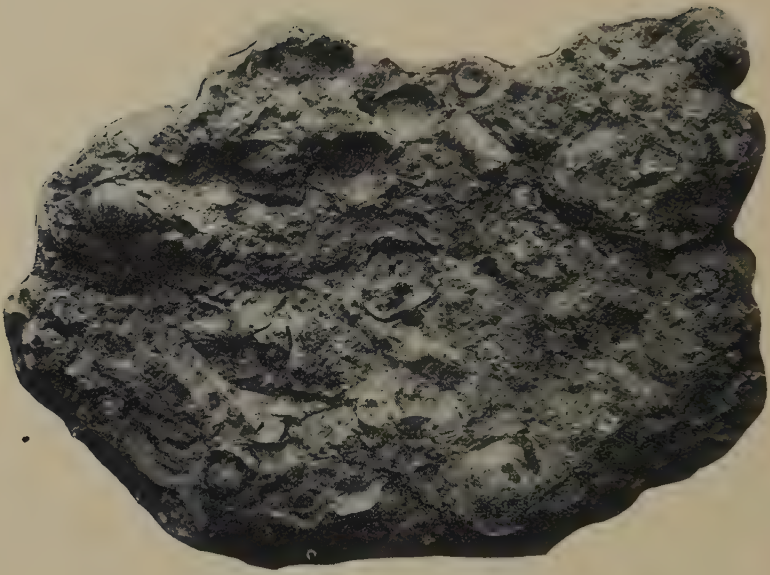
| | Loss $H_2O$ Per Cent. | Soluble $Al_2O_3$ Per Cent. |
|---|---|---|
| 1. Bauxite dried at 100° C., but otherwise uncalcined | Nil. | 59·00 |
| 2. Partially calcined | 12·55 | 57·60 |
| 3. " " | 18·55 | 57·10 |
| 4. " " | 26·60 | 53·10 |
| 5. Calcined | 32·15 | 20·40 |

From the percentage losses of water, which incidentally appear to be very irregular compared with Arsandaux's and my work, it is possible to hazard a guess that the partially calcined bauxite was not heated above 750° C. at the fourth stage, and about 300° C. at the second stage. Complete calcination was probably conducted at 900° to 1000° C.

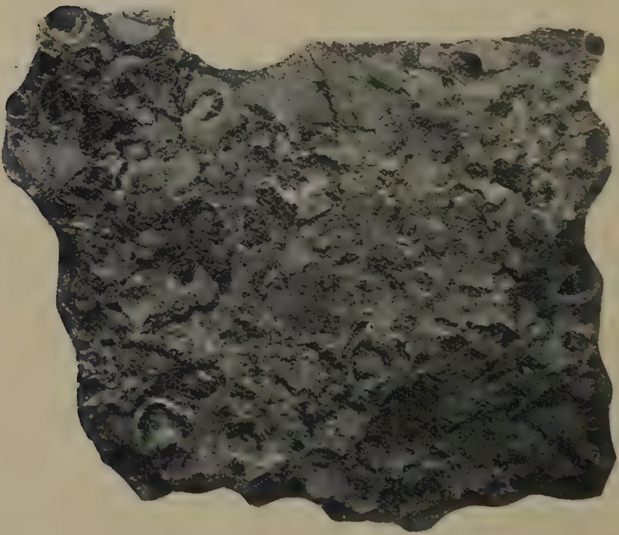
If the alumina in bauxite exists in a colloid (*gel*) form, it will impart the properties of a semi-permeable membrane to the zone in which it is present. Consequently, no colloidal silica and no ferric *gel* will be able to pass through such a zone, although ferric and other *salts* may readily negotiate such a membrane. This aspect of the condition of the alumina in laterite is thought to be of considerable importance, for, should a condition of dialysis become established, as it would appear it must do, then powerful capillary forces will become available, and chemical separations will be induced, both as a result of osmotic pressure and by the migration of electrically charged *sols* in an electrolyte (the acid or alkaline ground water). The hydro-*gel* of alumina is thought not to be as active as that of ferric iron (+) or silica (−), and evidently remains more or less stationary in the mass of the laterite. However unable it may be to control the movements of mineral salts, this colloidal alumina probably exerts a strong retarding influence on the migration of other colloidal particles.

**Pisolitic Structure.**—With regard to the pisolitic or oölitic structure so common in bauxite—those zones of bauxite which are exposed to the surface or lie in the paths of seepage surface waters—are very difficult to explain. The pisolites themselves may be cemented together in a hard matrix, or these pellets, often more than 2 inches in diameter, may lie in a soft powdery matrix. In the former case, the matrix is often found to be crystalline gibbsite. In both cases the pisolites have an amorphous texture, with frequently a concentric structure. There is little doubt but that this pisolitic structure occurs only close to the surface, at or a little above the height of the ground water level. There is also no doubt whatsoever that some alumina must be carried in solution by seepage waters, because it is not uncommon to find pisolites coated with alumina hydroxide

PHOTOGRAPH VII.



X.—Firm Grey Pisolitic Bauxite (India).



Y.—Soft Cream to Grey Pisolitic Bauxite (India).

which are highly ferruginous within. The opposite structure of a pisolite is more commonly encountered, showing that ferric hydroxide is frequently deposited on an aluminous core. In both cases of loose pisolites there is thus evidence of deposition and accretionary growth, but this explanation will not do for the pisolitic structure of hard massive bauxite. In this latter case accretionary action is thought to be subordinated by some selective action as the result of Liesegang phenomena.

Dr. A. M. Heron brought some pisolitic specimens of a rock overlying limestone near Chitorgarh, Rajputana, so exactly like bauxite that I was deceived as to its true composition, *i.e.* 40 per cent. silica in combination with alumina. It would appear to be similar in many respects to the highly aluminous pisolitic clay of Ayrshire, and to the diaspore pisolitic rock of Jammu. Dr. Heron is of the opinion that it is of superficial occurrence, and may represent the residual products (insoluble) of the limestone which has been lost in solution.

**Ferric Oxide.**—Ferric oxide appears to be closely related to, and almost invariably present with, alumina in laterite and bauxite. It is, however, more soluble and more easily precipitated. The presence of ochreous colours may be taken as an indication that the ferric oxide is present in the hydrated form, and almost certainly in a colloidal condition. It has, as a colloidal liquid *sol*, a similar positive electric charge to the hydrosol of alumina, and consequently the two tend to keep apart. It is possibly this influence which gives rise to the peculiar mottled structures of cream and brownish-red, so common in many laterites. Claims have variously been made as to the recognition of definite minerals having the composition of ferric hydroxide: thus limonite, xanthosiderite, and hematite (dehydrated) are said to have been observed. I have noticed hematite and strongly suspected limonite in a colloidal condition, but cannot vouch for the composition being limonite rather than any other hydroxide of iron. The tendency towards dehydration is strong, but it is possible that the colloidal material solates or gelates with easy reversibility between certain limiting conditions of temperature and humidity.

There is little doubt that the ferric oxide in the upper part of a laterite mass tends to concentrate at the surface and form a mantle of *cuirasse de fer* (Lacroix). It is thought that this concentration is effected by capillary action, in spite of the fact that, theoretically, it should not do so as a colloid in concentrated form. It is known, however, that as a colloidal *sol* this substance behaves differently according to its degree of concentration. A. W. Thomas and I. D. Gerard (*Jour. Amer. Chem. Soc.*, vol. xl, 1918, p. 101) have used this fact to prove the fallacy of the capillary method for the determination of the sign of the electrical charge of colloids. It had been generally accepted that negatively charged colloids would ascend strips of filter paper dipped into their dispersions, while positively charged colloids would not ascend, but would coagulate on the paper a slight distance above the surface of the dispersion. It has been since proved that, although this is true for negatively charged colloids in *dilute* dispersions and for positively charged colloids, *i.e.* ferric oxide, in the *concentrated* form, yet ferric hydroxide in a *dilute* dispersion ascends the filter paper as if it were negatively charged. As a crystalloid (salt) the ferric hydroxide would be unaffected by the above considerations. It could be precipitated from solution in various ways by suitable reagents, or sometimes by bacteria. Both D. Ellis and E. H. Harder have, separately and independently, shown that the so-called *iron bacteria* are misnamed as such : the existence and activities of these bacteria are not essentially dependent on the presence of iron (usually in solution). These micro-organisms are nourished by other substances, and the deposition of the ferric hydroxide that sometimes occurs is more incidental than otherwise. These forms of life live in marshes and pools, and affect the water supply of reservoirs, and are usually the cause of the sudden flocculent precipitations of ochreous (reddish-yellow) matter (limonite) in such waters. But these bacteria could not thrive on the scorched, bare surface of a laterite region during the dry monsoon, however suitable may be the climatic conditions during the wet season. Nevertheless, the presence of nodular agglomerated masses of pisolitic limonite in the *cuirasse de fer* zone of a laterite mantle suggests that ferric hydroxide is being deposited either by percolating water or under the influence of capillarity—probably both processes operate at different seasons.

In conclusion, it must be said that the predominant red, brownish-red, and pink tints so evident in laterite and bauxite are suggestive of the ferric iron being reduced to the oxide, or a dehydrated condition. Yellow and other yellowish tints are less evident in laterites, and rare in bauxites.

**Silica.**—The removal of silica during rock decomposition is probably the most characteristic feature in the chemistry of lateritisation. The difficulty of removing free quartz owing to its relative insolubility is well illustrated in the case of quartz geodes in laterite from certain basalts. (See *Mem. Geol. Surv. India*, vol. xlix, pt. 1, 1923, pp. 29-30.)

> The crystalline quartz is in most cases barely affected, the crypto-crystalline chalcedony is partly opaque and enamel-white ; whilst the opaline amorphous portions of the geodes are white and powdery.[1] The more severely altered geodes

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[1] As these geode fragments are found in the laterite at its surface, perhaps the mechanical breaking-up is assisted by the dehydration of the silica hydrates—chalcedony and opaline silica. Van Bemmelen (*Zeitschr. anorg. Chem.*, vol. xiii, 1896,

show a complicated network of cracks and peculiar joints. It can be easily imagined that in the course of time the whole geode would disintegrate, and the fragments would become too small to be recognisable as portions of a geode. The siliceous character would be detected by chemical analysis alone as the smallest fragments would show no crystalline structure. These minute portions evidently become absorbed into the laterite, and are later leached from it by the same agencies [1] which have removed the liberated silica of the silicate minerals of the rock.

Free silica is a not uncommon impurity in laterite formed from rocks containing free silica as quartz, *e.g.* granite, diorite, gneisses, etc., but it is an exceedingly rare component of a primary laterite formed from basic rocks such as basalts and dolerites (in which geodes are absent). Silica (quartz) is common in secondary or detrital laterites, and as secondary silica in some primary laterites. In the latter case there is usually evidence of the region having undergone subsidence as a result of which the laterite has been submerged and covered by deposits of sedimentary material, as is the case in some of the British Guiana occurrences.

The removal of silica liberated from the breaking down of mineral silicates is a simpler process, since this silica is usually in a soluble form. It is the considered opinion of many investigators that rock decomposition leads to the production of *gels* or mixtures of *gels*. These colloids are *not* amorphous alumino silicates, but simple *gels*, possibly mixed, due to the mutual precipitation of positive and negative *sols*. The acceptance of such an explanation removes the

p. 233) has discussed the hysteresis of the hydration and dehydration of the silicic acid *gel*. As dehydration proceeds the *gel* becomes white as porcelain and then opaque, but if the process is continued the substance becomes white and opalescent and finally clear; the same order of stages takes place on hydration. According to W. W. Taylor, the *sol* of silicic acid is unstable and the stability is affected by acids and alkalies, as is also the sign of the electric charge on the colloid. It is therefore possible, by suitably treating a solution of colloidal silica, to cause the hydro *sols* to have negative or positive charges as compared with some unalterable datum of electric potential. This is done on a practical scale in the purification of clays.

[1] Clarke, in his *Data of Geochemistry*, states that waters draining from regions of decaying vegetation may contain a series of vegetable acids—cremic, apo-cremic, ulmic, humic, etc.—whose precise chemical relations are unknown, but which are capable of dissolving silica. Humic acid is said to be able to decompose silicates and to form, by reactions with the ammonia in rain-water and nitrogen from the air, a series of silico-azo humic acids which are soluble. Azo-humic acids in the presence of alkaline carbonates are capable of dissolving silica. J. B. Harrison has detected appreciable percentages of silica in the water draining certain tracts of the laterite areas of British Guiana, and Clarke notes two classes of water which are characterised by a high silica content:—

(*a*) Tropical streams containing large proportions of organic matter usually carry large quantities of silica.

(*b*) Certain small streams near their sources carry relatively large proportions of silica. This silica is derived directly from the rocks at the time of their decomposition by carbonated waters, and forms a large part of the material first taken into solution.

difficulty of trying to account for the disintegration of the hydrated silicates, or the so-called second stage in the production of hydroxides from original silicates. It is evidently a single process, but complicated by the fact that the colloidal hydroxides carry electrical charges, and, if given freedom of movement, say as *sols*, migration of the colloids can be caused by the production of a difference of electrical potential.[1]

---

[1] The positive *sols*, ferric hydroxide, hydroxide of aluminium, chromium hydroxide, and titanic acid, although repelling each other, will migrate differentially to the cathode, whilst negative *sols* like silicic acid and vanadium pentoxide will be attracted to the anode. If there is no freedom of movement, negative and positive *sols* will attract each other and precipitate together as single *gels*. In the nascent stage of the formation of clays possibly the above action takes place, whilst in laterite formation there must be both freedom and directive movement of the most conspicuous, *sol*, *i.e.* silicic acid. Speaking of the artificial purifying of clays, A. B. Searle ("Clays and Clay Products," Third Report on colloidal chemistry and its general and industrial applications: *Rep. Brit. Ass.*, 1920, pp. 113-153) says:—

"The separation of the impurities is due to the fact that whenever a charged colloid particle in suspension meets another similarly charged particle they mutually repel each other and so remain in suspension. When two particles of opposite charge come into contact, the charge is neutralised, and the two particles unite and are precipitated. The electrolyte (sodium carbonate or caustic soda) added must, therefore, be one which will increase the negative charge of the material as a whole, so as to effect the precipitation of the impurities (which are chiefly electro-positive), and retain in suspension the electro-negative particles of clay and, along with them, some silica which is also electro-negative. The coarser particles of silica, pyrite, felspar, mica, etc., do not become charged, but settle on account of their size and weight. If the liquid is too viscous, the impurities will not settle properly, and it must then be diluted until the density and viscosity are such that sufficient separation is effected without the loss of clay by sedimentation" (p. 145).

[In the Schwerin electro-osmosis process the clay is] "caused to migrate to a rotating electrode immersed in the liquid and is scraped off in the form of a stiff paste. Schwerin found that all clays did not behave thus, and only migrated so when they carried an electric charge. This charge is supplied, in some cases, by the addition of organic colloidal matter, such as humic acid, prior to the use of alkali.

"The apparatus for treating clays consists of a wooden trough with one electrode of wire gauze, and the other a metal drum rotating in the trough containing the alkaline clay slip. The electric current is then passed through the fluid, using the gauze and drum as poles. In this apparatus, a further slight purification is effected owing to the tendency of the impurities to travel to one electrode, whilst the clay (with some silica) travels to the other. The clay and finest silica particles assume a negative charge, but that of the silica is so slight that the silica remains almost stationary in the fluid, whilst the clay travels to the anode. Pyrite, alumina, and ferric oxides are positively charged and travel with the water towards the cathode. The dominant feature in the speed of migration is the valency of the material attracted to the diaphragm" (p. 146).

"A possible method of purifying clay and separating the colloidal silica is due to Billitzer (1905), who found that in N/2 to N/10 solutions of hydrochloric acid, the charge of colloidal silica is changed from electro-positive to electro-negative, so that the careful addition of acid should enable a practical separation of colloidal silica from colloidal clay to be made" (p. 146).

**Lithomarge.**—The silica in, or associated with, bauxite or laterite is usually in a state of combination. The lithomarge zone (see Fig. 7) below the laterite probably represents the manner of combination; in this zone, however, siliceous bands of ferruginous matter are also common. From field observations, as in the good exposures seen at the Bagh Dewaza in Panhala Fort, Kolhapur State (India), there is little doubt of the genetic relationship between the bauxite I, the lithomarge II and III, and the kaolinised trap IV. See analysis below:—

| | I | II | III | IV |
|---|---|---|---|---|
| $SiO_2$ . | ·80 | 42·79 | 40·97 | 37·31 |
| $TiO_2$ . | 3·23 | 9·08 | 6·44 | 3·33 |
| $Al_2O_3$ . | 64·77 | 23·96 | 22·97 | 27·85 |
| $Fe_2O_3$ . | ·31 | 7·89 | 13·41 | 17·35 |
| MgO . | Trace. | 1·54 | 2·00 | ·76 |
| $H_2O$ . | 31·54 | 14·73 | 14·77 | 13·40 |

Analyses of the bauxite, however, stand in striking contrast to the lithomarge a few feet below. The variable composition of the white lithomarge is also remarkable.

| | V | W | X | Y | Z |
|---|---|---|---|---|---|
| $SiO_2$ . . . . | 78·26 | 64·85 | 45·41 | 46·75 | 49·54 |
| $TiO_2$ . . . . | ? | — | 11·20 | 39·59 | |
| $Al_2O_3$ . . . . | 19·15 | 22·05 | 24·90 | | 35·08 |
| $Fe_2O_3$ . . . . | | 2·80 | 2·10 | | 3·64 |
| MgO . . . . | 2·72 | 1·08 | 1·37 | ·22 | Trace. |
| | | | | Alkalies. | |
| CaO . . . . | Traces. | 1·45 | 1·10 | ·58 | ·40 |
| Loss on ignition . | ? | 5·12 | 12·34 | 12·70 | 12·13 |

V Clay exposed a short distance below bauxite of Murwara hill, Katni, India.
W ,, ,, ,, ,, ,, Tikuri, near ,, ,,
X ,, ,, ,, ,, ,, Tikaria, ,, ,, ,,
Y ,, ,, ,, ,, ,, Sirendag, Ranchi district, ,,
Z ,, ,, ,, ,, ,, Jamirapat, Sirguja, ,,

Samples V and W are evidently impregnated with free silica. It is not unusual to find beautifully clear doubly-terminated quartz crystals in association with the Murwara hill (V) horizon. The high titanic content of X suggests precipitation from solution. The samples Y and Z are normal kaolinite.

A lithomarge zone is found in almost every occurrence of laterite or aluminous laterite, whether it be on the Darling Range of Western Australia, the frowning scarps Panhala Fort in the Deccan of India, the forest-covered slopes of the Vogelsberg in Germany, or the coastal region of British Guiana. There is no question as to any doubt about a genetic relationship between the overlying laterite, the lithomarge, and the underlying altered rock. But it is clearly evident from certain exposures in India that much of the lithomarge has been carried in suspension by percolating water and deposited at the basal margin of the laterite, but within the body of the laterite, as depicted in Fig. 7.

The analyses given above show that the lithomarge of different exposures is contaminated with additional silica and titania. Sir John Harrison has been working at the problem of this kaolin with regard to occurrences in British Guiana. He has tested the solubility of this material in slightly alkaline solutions (sodium or potassium hydrate), and precipitation with ammonium chloride obtained products which were invariably mixtures of *gels* and not kaolin as we know it. Sir John further found that the most reliable mode of determining whether a hydrated mineral substance was colloidal or otherwise was as follows.

By very slowly heating the finely powdered substance in an electric furnace

> and noting the temperature at which it parted with its colloidal or its crystalline water of constitution.

He found that

> colloidal substances gave off their water slowly and continuously parting with the final fraction of it only at very high temperatures.

He also noted that

> crystalline bauxite, including both gibbsite and aluminous laterite, gave off very little water until they arrived at a critical temperature of approximately 250° C. By far the greater portion of the water was given off at this fixed temperature, a thermometer immersed in the powdered substance ceasing to rise until the water had been driven off. This check in the rising temperature clearly defines that at which the water of crystallisation is driven off. Even with these crystalline products some water is retained until a very high temperature is reached. With kaolin-like products [1] the temperature has to be raised to from 600° to 650° C. before water is given off in quantity. There is a check in the rise of temperature at about 625° C., which marks the decomposition of the kaolin. In some clays containing halloysite the water of constitution commenced to be evolved at about 450° C.

Sir John Harrison's results are similar to mine, but we have drawn different conclusions (compare above with *Mem. Geol. Surv.*

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[1] In the paper by Searle, referred to previously, that ceramic chemist says (p. 144): "It is now fairly well established that many of the properties of clays are closely connected with the colloidal matter present, such matter being in the form of a film of colloidal *gel* surrounding particles which are of a non-plastic or colloidally inert nature; in some cases they may be rich both in alumina and silica—as in china clays and ball clays—whilst in others they may be almost wholly siliceous, as in fire-clays and many brick earths."

*India*, vol. xlix, pt. 1, 1923, p. 22). Yet I am prepared to agree that colloidal *sols* gelatinate (give up water) gradually, whereas water of constitution or crystallisation is only evolved at a definite temperature. Consequently my determinations, as well as those by H. M. Arsandaux, very definitely establish two "arrest point" temperatures, and would appear thus to indicate very little colloidal matter as being present. With this conclusion, of course, I cannot agree. Most of my bauxites gave up the greater part of their water at about 650° to 700° C.—which is Sir John's kaolin point—whereas my bauxite is almost silica free. The subject of the composition and nature of clays offers an attractive if complex field for study—we really know very very little about clays from a chemico-physical point of view.

**Combined Water.**—Sir John Harrison's conclusions on this point have already been given under the section on "Lithomarge," above. However, from data which are gradually accumulating, it would appear that the water held in a state of combination in bauxites from all parts of the world—India, France, Russia, etc.—behaves as though it were part of a definite compound, *i.e.* water of constitution partly, and water of crystallisation where gibbsite has been recognised. This water comes away at definite temperatures, and not gradually, as one might expect from a colloidal material.

Two samples of Indian laterite—(A) grey pisolitic bauxite ; and (B) yellowish-red pisolitic limonite (?)—were crushed, sieved, and the products heated for two hours at 800° C., and then for an hour at white heat with the following results :—

| Size of Mesh. | Temperature. | Grey Bauxite. | Limonitic Laterite. |
|---|---|---|---|
| | | $H_2O$ Loss. | $H_2O$ Loss. |
| | | Per Cent. | Per Cent. |
| + 40 . . . | 800° C. | 24·26 | 15·0 |
| | Over 1000° C. | 25·75 | 17·48 |
| + 60 }<br>− 40 } . . . | 800° C. | 24·95 | 16·55 |
| | Over 1000° C. | 26·21 | 18·33 |
| − 60 . . . | 800° C. | 25·46 | 17·15 |
| | Over 1000° C. | 26·23 | 19·91 |

This experiment shows how firmly the water of combination is held by the alumina and ferric oxide. It was thought that perhaps the bauxite might consist of hydroxide *gels* of the composition of diaspore, di-hydrate and gibbsite, and that some evidence for this possibility might be obtained by carefully heating the bauxite to various temperatures from 100° to 1000° C. and over.

On an average sample of bauxite the following figures were obtained :—

| | |
|---|---|
| 30° to 250° C. | $H_2O$ loss equals 2 to 4 per cent. of the total water. |
| About 265° C. | ,, ,, 25 ,, ,, ,, |
| 270° to 600° C. | ,, ,, 26 ,, ,, ,, |
| Between 650° and 750° C. | ,, ,, 96 ,, ,, ,, |
| At white heat | all $H_2O$ driven off. |

It would thus appear that there are two definite points, 260° C. and 700° C. approximately, at which large volumes of water are given off. The first agrees very well with the destruction temperature of crystalline gibbsite, but of the other, the larger evolution of $H_2O$, nothing definite is known. H. M. Arsandaux has carried out similar experiments on French bauxite, and the above results agree very well with those he has obtained. The ferruginous laterites behave in a normal manner, and have not shown any characteristic features.

In the case of the experiments on calcination and solubility of alumina in American bauxite, by Phillips and Hancock (1898), the data (previously given) suggest that the water was given off gradually, while the alumina insolubility suddenly increases at a moderately high temperature, and appears to indicate that a critical temperature of some kind certainly exists.

**Other Constituents.**—It is evident from the various analyses of bauxite that a number of other constituents—usually original accessory components in the rock, but occasionally secondary enrichments in the laterite—are found in bauxite. Many of these constituents, *e.g.* lime and magnesia (possibly as carbonates), sulphur and phosphorus, and chromium and vanadium, are not present in appreciable amounts, and have merely an academic interest. They give clues of a kind as to the nature of the rock which has been lateritised in the formation of the bauxite.

The following minerals have been found in the bauxites of Arkansas and Central Georgia : zircon and pyrite ; while the rare felspar celsian, and the minerals barytes and fluorspar have been found in the bauxite of the former State, and apatite and ferromagnesian minerals in that of the latter. All these occur in the underlying rocks, respectively, from which the bauxites have evidently been formed.

**Titanium.**—Titanium, usually shown as $TiO_2$ in chemical analyses, and possibly present as a hydroxide, is occasionally present in large amount in certain Indian bauxites, and seldom absent from any bauxite. It is to be considered as an insoluble residual component of the original rock, having been present as a titaniferous mineral, *e.g.* ilmenite, or some such form.

In a later chapter attention is drawn to the possible recovery of the titania from the ferruginous slime waste in the Bayer process of preparing aluminium hydroxide from bauxite. The titanium dioxide thus obtained may, as a cheap product, find a ready market in the paint industry for the manufacture of durable opaque and harmless dead white paint.

**Manganese.**—Manganese as psilomelane and pyrolusite has been found in association with botryoidal hematite in the laterite of Gosalpur, Jabalpur district (India), but otherwise manganese compounds do not appear to be predominant in laterites, and are distinctly rare in bauxites.

**Cobalt and Nickel.**—Cobalt and nickel occur in very small percentages in the lateritic iron ores of the Oriente Province of Cuba, in the neighbourhood of Nipe Bay. The lateritic ore is quarried in the Mayari and Moa districts, but for its iron, not as bauxite. So far as I know, cobalt and nickel have not been found in more than mere traces, if even so, in the bauxite of any area.

**Tin.**—Tin in the form of tinstone or cassiterite is found in workable amount in certain quartz stringers in the laterite about Liruie, in Northern Nigeria (*Min. Mag.*, Dec., 1922, editorial, and pp. 345-348). The following extract is made from the editorial above noted :—

> Messrs. G. Gordon Thomas and J. L. Vitoria give a description of an occurrence of tin-bearing veins in the Liruie Hills, Northern Nigeria. These deposits are of considerable scientific interest, inasmuch as some of the veins are in laterite. The main veins contain cassiterite, wolfram, blende, copper pyrites, and columbite, in a quartz gangue, and they traverse the margins of an intrusive granite. In addition to these veins, there are irregular quartz stringers, containing cassiterite in a laterite overlying the granite. Presumably the granite has been lateritised in situ, while the quartz veins have been only partially attacked. To those who are familiar with the characteristics of laterite, the presence of these undigested stringers of quartz will be fairly well understood. Crystalline silica is remarkably insoluble at all times, even when exposed to lateritisation conditions, and large fragments of quartz persist as corroded aggregates in the oldest laterites. The notable point in this case is that cassiterite should occur in association with the lateritised quartz, for it is a much more soluble mineral. One is led to the belief that the cassiterite in these stringers has been precipitated subsequently to the lateritisation ; that is to say, that it is not a primary constituent of the lateritised veins, but was deposited after the original tinstone of this part of the veins had been removed. The quartz stringers would by their disposition maintain regular channels for the passage of water up and down during the process of lateritisation. Infiltrating waters would dissolve the soluble constituents, while upward percolating waters would carry the dissolved substances to the surface. In tropical countries where there is severe evaporation the spring waters would readily deposit the minerals held in solution, and in this way cassiterite would be brought upward into the zone above permanent ground-water level.

It is to be remembered, however, that here again we are dealing with ferruginous laterite and not bauxite. So ferruginous is this material, that Dr. J. D. Falconer, Director of the Geological Survey of Northern Nigeria, avoids using the term laterite for it, and designates it as surface ironstone.

**Gold.**—Native gold has long been known to occur in the laterites of the north-western district of British Guiana, in association with veins and threads of quartz. These may have the same mode of origin as that ascribed for the stringers in the Liruie laterite of Nigeria. However, the opinion of so great an authority as Sir John Harrison seems to be that this quartz is secondary, the silica having come from the lateritisation of diabase, epidiorite, etc., in the vicinity. The gold is evidently an original constituent of the gneissose rocks which had been lateritised, and the gold has remained as a residual component in the laterite.

**Silver.**—Curiously enough, gold has been found in the lateritic bauxites of the Mt. Supirri area of the Gold Coast (West Africa). Silver is associated with this gold

> " in appreciable quantity, and it is suggested that if the alumina is dissolved out by a process such as the Bayer, a residue will remain carrying enough of these metals to make their recovery worth while." (W. G. Rumbold, " Bauxite and Aluminium," 1925, p. 65. See original in *Govt. of Gold Coast, Rept. Geol. Survey*, 1921.)

There is little doubt that the gold and silver of this tract, which lies in the property of the Affoh Gold Mining Concessions, are the undigested residual constituents from the rocks, with their auriferous veins, etc., which have been lateritised.

**Diamonds.**—Considerable interest in British Guiana is attached to the extraction and collection of diamonds from a lateritic matrix, which is associated with pre-Cambrian strata (Kaieteurian sandstone). Further particulars regarding this occurrence are not yet to hand. The following extract is taken from *Handbook of British Guiana*, 1922 (p. 26), which, discussing " Diamonds," says :—

> The original source of the diamonds found in the colony is not known. There are indications in some districts that they have been derived directly from the degradation of basic rocks, while in others they may have been originally derived from such sources, whence they found their way into parts of the sandstone formation, and thence by degradation and detrition of the rocks into the gravels in which they are now found. Of late years the exploitation of the diamantiferous deposits has become a very important and lucrative industry.

**Carbon Dioxide.**—A. E. Kitson has recorded that appreciable quantities of $CO_2$ are emitted from the bauxite of Mt. Ejuanema on the Kwahu plateau (Gold Coast), so much so that many prospecting pits cannot be entered until previously ventilated. The bauxite is associated with almost horizontal beds of shales, with sandstones interstratified.

Practically all bauxites (laterite) give off minute or larger quantities of $CO_2$ when strongly heated. The source of this, as regards

Indian bauxites, is evidently the $MgCO_3$ which appears to be present in most bauxites derived from basalt. No indications of organic carbon, although carefully looked for, have been so far found in Indian bauxite.

**Carbonaceous matter** has been found with the bauxite of North-West Georgia (Appalachian area). These ores occur in intimate association with the Knox dolomite, and may possibly be a residue of the dolomite. Carbonaceous matter is frequently present in limestones, and has been reported to occur in some French bauxites. (C. Mortimer, *Aluminium*, 1919, p. 23.)

# CHAPTER V.

## MODE OF FORMATION AND ORIGIN.

### The Origin of Laterite.

There are few petrological problems which have proved so difficult of solution as the mode of formation and genesis of laterite. The literature on the subject of laterite is, as seen from the attached bibliography, very extensive, and it is steadily increasing. Since 1807, when Buchanan (— Hamilton) first drew attention to the laterite of Southern India, and on to the present day, there has been no agreement as to the detailed manner in which laterite is formed. General conclusions have certainly been arrived at, more by processes of elimination of certain theories, and the modification of those which agree more closely with the observed evidence, than by any carefully conducted experimental determinations. The nature of the problem, involving as it does, as essential factors, slow changes during vast periods of time, possibly renders any determinative method, as a conclusive test, unsatisfactory.

**Lacustrine Deposits.**—Among the earlier views put forward for laterite formation, and which have received support subsequently, were those of F. R. Mallett (*Rec. Geol. Surv. India*, vol. xiv, 1881, pp. 139-148), in his paper on the "Iron Ores of North-East Ulster (Ireland)," in which he compares the Indian laterite with these Irish iron-clays (now called bauxite). He considered the Irish beds as belonging to a single horizon by which the basaltic lavas of Antrim could be divided into two great series. The intra-trappean beds were associated with sediments containing evidence (plant remains) of a warm or sub-tropical climate during the Miocene epoch. The sediments, as well as the iron-clay bed, were thought to have been formed in a lake. From the analogy Mallett concluded that the Indian laterite must also have been formed in lakes. J. W. Spencer (*Geol. Surv. Georgia*, "The Palæozoic Group," 1893, p. 214) regarded the bauxite of Alabama-Georgia as a lagoon deposit, thus making bauxite the equivalent of bog iron ore. E. W. Wetherell (*Mem. Mysore Geol. Dept.*, vol. iii, pt. 1, 1906, pp. 1-27) came to similar conclusions with regard to the origin of laterite in Mysore (India), and R. C. Burton (*Rec. Geol. Surv. India*, vol. xlviii, pt. 4, 1917, pp. 204-218) discusses the bauxite-laterites of Seoni in the Central Provinces (India) as lake deposits. However, Mallett had very considerably modified his opinions by 1883, when he published an account of the Manganese ore in the laterite of Gosalpur, Jabalpur district, Central Provinces, and suggested a threefold classification for types of laterites :—

1. Due to deposition.
2. Alteration of rock *in situ*.
3. Detrital or redeposited. (See *Rec. Geol. Surv. India*, vol. xvi, 1883, pp. 116-118.)

**Liberation of Iron Salts.**—W. J. McGee (*Geol. Mag.*, Decade II, vol. vi, 1879, pp. 353 and 412 ; also vol. vii, 1880, p. 310) compared the ferriferous deposits of the Upper Mississippi basin with the Indian laterites. He favoured the mode of formation as being due to the solvent action of vegetable acids on the ferruginous soil, *i.e. in situ*. He considered that accumulation of this material would depend on—

(1) The solubility of the basal rock ;
(2) The proportion of contained iron ;
(3) The fertility of the soil formed by its disintegration ; and very largely on
(4) The climate of the region.

J. Walther (*Verhandl. Gesell. Erdkunde*, vol. xvi, 1889, p. 318) laid great stress on the introduction of nitric acid during thunderstorms with tropical rain. He considered that certain easily hydrolysed iron salts were formed as a result of the interaction of the acid. These iron salts effected the lateritisation of the rocks *in situ*.

S. Passarge ("Report of the Sixth International Geographical Congress, London," 1895) discusses, in *Uber Laterite und Roterden in Africa und Indien*, the formation of laterite in a similar way to that suggested by Walther, but he considers that there are several factors in addition to the nitric acid which has been introduced from atmospheric sources into the soil ; the iron containing minerals in the rock ; the abundance of the covering vegetation ; the activity of micro-organisms or the humus of destructive termites, and the presence of rain-worms, which assist humus formation.

**Micro-Organisms.**—The idea of bacteria operating in the formation of laterite was independently elaborated by Sir Thomas Holland ("The Constitution, Origin, and Dehydration of Laterite," *Geol. Mag.*, Decade IV, vol. x, 1903, pp. 59-69.) He says :—

> The action of some lowly organism having the power of separating the alumina, which, after the manner of many plants, it does not want, from the silica which is necessary for its life, but which, being in a soluble form, is removed again by the alkaline solutions. Such a form of life might thrive in the moist climate of the tropics, even to a temperate altitude, but find life intolerable in a land subject to severe winters, such as we get in the temperate zone and in North India, where we find no laterite.

This aspect of laterite formation is most intriguing from several angles, particularly from the point of view of rock decomposition and the formation of clays. However, very little work has been done on the clays and soils of moist tropical countries from this point of view, so that there is little or no data to build upon at present. In my work on Indian bauxite, I was unable to discover any trace of hydrocarbons or organic matter in the material examined by me.

The subject of laterite formation is broadly discussed by R. D. Oldham in his *Manual of the Geology of India*, second edition, 1893, pp. 369-390. The evidence reviewed by Oldham of the facts collected in India by various observers largely suggests that laterite is the direct residual weathering product, under peculiar conditions, of various rocks—dolerite, granite, gneiss, etc., but not pure limestone or sandstone. These conclusions support the views put forward by Phillip Lake (*Mem. Geol. Surv. India*, vol. xxiv, 1890, pp. 217-233). This opinion was exactly the same as that adopted by Max Bauer when he found that laterite and bauxite were varieties of the same type of rock—the laterite more frequently on basic rocks and the bauxite commoner on acid rocks (*Neues Jahrb.*, 1898, Band 2, p. 192). It was thought by some observers, notably E. C. J. Mohr and J. B. Harrison, that lateritisation occurred principally in those rocks which contained plagioclase feldspars (*Geol. Mag.*, 1910, pp. 439, 488, and 553).

**Hot Springs.**—During the same period, 1883 to 1903, the opinions in the United States (C. W. Hayes, etc., *Sixteenth Ann. Rept., U.S. Geol. Surv.*, pt. 3, 1895, p. 547) centred round solfataric action with regard to the origin of the bauxite which had been found in Arkansas, Georgia, and Alabama. In the case of the Arkansas bauxites, which were considered to be no older than Tertiary age, the several observers concluded the bauxites were formed as the result of the action of strong alkaline or saline waters on the felspathic components of heated syenite. This view agreed with ideas advanced by G. A. Cole in connection with certain bauxites in Ireland. He thought they must be due to the decomposition of intrusive rhyolites by acid vapours with production of soluble alumina, which material was finally precipitated by alkaline carbonates (*Trans. Roy. Dublin Soc.*, 2nd series, vol. vi, 1896, p. 105). Hayes had noted gibbsite in the bauxite of Georgia, and attributed its formation to heated ascending waters, which had decomposed pyrite in the underlying shales (*Trans. Am. Inst. Min. Eng.*, 1894, p. 243). A similar explanation, *i.e.* the intervention of sulphates, from pyrite or sulphuric acid, in producing soluble alumina which is precipitated at or near the surface by carbonate of lime, was offered by other writers for the origin of bauxite in other fields—

A. Liebrich, in Germany, for the Vogelsberg bauxite, etc. These writers appear to have been greatly influenced at the time by the discoveries of (1) Blake in the Upper Gila River, New Mexico, where bauxite was said to be found in association with alunogen (*Trans. Am. Inst. Min. Eng.*, vol. xxiv, 1894, p. 573); and (2) W. Cross, at Rosita Hills, Colorado, where rhyolite was found altered to a quartz-alunite and a quartz-diaspore rock (*Seventeenth Ann. Rept.*, *U.S. Geol. Surv.*, pt. 2, 1896, p. 314).

French writers of about 1883 had concluded that the bauxites of Provence were deposits from hot springs, but their conclusions were, according to F. W. Clarke (" Data Geo-chemistry," 4th edition, *U.S. Geol. Surv. Bull.*, 695, 1920, p. 491), based on erroneous data.

**Sulphuric Acid.**—The idea of alumina being leached from rocks containing aluminous minerals by waters containing free sulphuric acid (and from which the alumina was precipitated near or at the surface by waters containing calcium carbonate) was revived by G. C. Du Bois (*Tscherm. Mitth.*, vol. xxii, 1903, pp. 1-61). He made an intimate study of the laterite of Surinam (Dutch Guiana), and noted the presence of iron pyrite in the diabase (altered dolerite), from which the primary laterite was obviously derived. Du Bois ascertained the presence of free sulphuric acid (0·47 to 0·53 per cent.) in certain primary laterites, and as a result he came to the conclusion that sulphuric acid must be the essential factor in the formation of laterite. He says (*translated*) :—

> The source of laterite (*secondary or sedimentary*) of alluvial formation might therefore be traced as a formation analogous to the origin of deposits of alumstone. By the formation of sulphuric acid (which arose either by the decomposition of iron-pyrites or by exhalations of $H_2S$ and $H_2SO_4$, and which worked upon the felspars of the trachyte and other solid rocks) there arose a product of transformation rich in aluminium hydroxide. Passarge mentions that on the South African plateau the phenomenon of non-laterite-forming rocks has not yet been explained. The thought is very obvious that the explanation might be sought in the want of pyrites, or, at any rate, of sulphuric acid.

**Deposition by Upward Subterranean Waters.**—The action of upward alumina carrying waters was insisted upon by Dr. J. M. Maclaren. He regards laterite as not directly a weathered rock residue so much as due to replacement. He rightly considers that a genetic theory must account for :—

(1) The restriction of the deposition of laterites, both geologically and in altitude.
(2) The general superficial occurrence of laterites.
(3) The porous, vesicular, pisolitic, or concretionary structure of laterite.
(4) And the peculiar composition of laterite as regards—
  (*a*) The essential aluminous, ferruginous, or manganiferous hydrates or oxides;

(*b*) The general presence of titanium dioxide; and

(*c*) The marked absence of kaolin or silica.

Dr. Maclaren, whose remarks chiefly apply to Indian observations, makes a great point of capillary action and segregation resulting from surface evaporation. It must be stated that he was particularly concerned with a rather exceptional instance of laterite formation—the Talevadi occurrence in Belgaum. His conclusions, however, are that:—

(1) Laterite deposits are restricted geographically, because they require for their formation—
   (*a*) Tropical heat and rain with concomitant abundant vegetation; together with
   (*b*) Alternating dry and wet seasons.

(2) Their restriction in altitude is only apparent. Their present lines of altitude merely mark ancient or existing basin floors or plains.

(3) They are derived from mineralised solutions brought to the surface by capillarity, and are essentially replacements (either mechanical or metasomatic) of soil or of rock decomposed *in situ*, or of both.

(4) In the humid regions of India the tendency of change in laterites is towards hydration, and not towards dehydration.

Dr. J. Morrow Campbell, after an extensive experience in West Africa, found that the opinions expressed in the publications of the Geological Survey of India were

> "in conflict with the phenomena of laterite formation as observed in Africa." "The Origin of Laterite," p. 432. See *Trans. Inst. Min. Met.*, vol. xix, 1910, pp. 432-457.)

He was unaware of the conclusions published by Dr. Maclaren, and came to almost identical conclusions himself. He says:—

> Laterite is a porous rock, formed above low water-level in the strata on low-lying slopes by the gradual removal of some, or most of the mineral constituents of either alluvium or rock *in situ*, and of the deposition therein of ferric and aluminous hydrates from mineralised water coming from below, the deposition being determined by contact with atmospheric oxygen.

Dr. Campbell's paper is a most important contribution. There are certain statements which are pregnant with meaning. He says, speaking of observations in Haute Guinée:—

> Water issuing from underground at all seasons deposits ferric hydrate and gives off carbon dioxide upon exposure to the air. Spring water in the tropics is well known to be more highly carbonated than in higher latitudes. Carbon dioxide has been supposed to be derived from the decomposition of vegetable matter. Both atmospheric carbon dioxide and that derived from decomposing vegetation doubtless pass underground in solution in rain-water and perform their part in decomposing minerals. Alkaline carbonates are also formed in the decomposition of vegetable matter, and, as far as laterite is concerned, they probably perform the most important

rôle.[1] . . . It is well known that a weak aqueous solution of alkaline carbonates, at ordinary temperatures, attacks silicate of alumina, removing silica in solution, with the liberation of carbonic acid, and that it dissolves alumina as well. The alkaline silicates are stable compounds, whereas the aluminates are very unstable, being decomposed by carbonic acid. Selective action results in the combination of the alkalis with silicic acid mainly, and the separation of alumina, which remains behind as its amorphous hydrate, bauxite.

Maclaren and Morrow-Campbell's views have received support from J. H. Goodchild (*Trans. Inst. Min. Met.*, vol. xxiii, 1913, pp. 2-54), whose work in Brazil led him to the belief that the *canga* of Minas Geraes was due to the action of heated subterranean waters, and the process was one of lateritisation. His opinion that the *canga* is laterite is established by the following analysis, which is obviously that of an aluminous laterite :—

| | |
|---|---|
| $SiO_2$ . . . | 1·25 per cent. |
| $Al_2O_3$ . . . | 49·02 ,, ,, |
| $Fe_2O_3$ . . . | 21·48 ,, ,, |
| $Mn_3O_4$ . . . | Trace. |
| CaO . . . | 0·35 ,, ,, |
| MgO . . . | 0·20 ,, ,, |
| Loss on ignition. . | 28·40 ,, ,, |

In the discussion which followed this paper, an experienced Indian geologist, Mr. R. D. Oldham, gave it as his opinion that monsoon conditions were not essential for the formation of laterite, but emphasised the importance of continually moist or semi-desert climates.

**Sub-aerial Weathering.**—The American bauxites have been carefully investigated by C. K. Leith, and especially W. J. Mead (*Econ. Geol.*, vol. x, 1915, pp. 28-54), who came to the conclusion that at least those of Arkansas must be the result of the surface weathering of syenite, and not due to the action of hot mineral waters on heated syenite.

C. K. Leith and W. J. Mead, in two valuable papers (*Trans. Amer. Inst. Min. Eng.*, vol. xlii, 1912, pp. 90-102 ; and *Bull.* 103, July, 1915, pp. 1377-1380) in regard to the lateritic iron ores of Cuba, throw considerable light on the variation in the composition of the laterite. In the former paper they speak of the principal impurity of the iron ores as being bauxite (which gives no trouble in smelting). In smaller amount there is kaolin present. Bauxite increases in percentage towards the surface, while the kaolin decreases. They are agreed that these ores are residual or mantle deposits resulting from the surface alteration of serpentine rock, which in turn probably represents the alteration of some other rock, like peridotite, not yet disclosed by underground exploration. In the latter paper they give the following data. Starting from the unaffected serpentine rock below (30 feet from the surface) it is seen that magnesia (MgO) and silica ($SiO_2$) are rapidly lost. The MgO (33·69 per cent.) practically disappears at a distance of 5 feet above the serpentine rock. The $SiO_2$ (39·80 per cent.) is reduced to 3·66 per cent. 10 feet above the serpentine rock, and falls to 1·42 per cent. near the surface (26 feet above), where there appears to be a secondary enrichment to 2·58 per cent. Alumina ($Al_2O_3$), 1·39 per cent., ferric oxide ($Fe_2O_3$), 10·14 per cent., and chromium (Cr), ·20 per cent., rapidly increase in percentage with the loss of $SiO_2$ and MgO. $Fe_2O_3$ reaches a constant maximum percentage when the $SiO_2$ reaches its minimum. At 10 feet from the surface the $Al_2O_3$ shows increased concentration, while $Fe_2O_3$ and Cr show a more gradual curve than below. This increase of $Al_2O_3$, 10 feet from the surface, marks the maximum of $Fe_2O_3$ percentage due probably to secondary enrichment. Nickel (Ni) and Cobalt (Co) (·97 per cent.) show a gradual loss up to 10 feet from the surface, then a rapid one to ·38 per cent. Phosphorus (P) and sulphur (S) increase gradually from ·001 and ·06 to ·016 and ·12 per cent. respectively.

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[1] It will be remembered that Sir Thomas Holland dwells on the importance of alkaline solutions for the removal of the soluble silica.

In a subsequent publication, *Metamorphic Geology*, 1915, pp. 25-44, Leith and Mead discuss the bauxite as formed from syenite and the lateritic iron ore as from peridotite, and indicate fairly clearly that they favour a sub-aerial mode of weathering of the rocks concerned to produce the substances bauxite and laterite.

A. Holmes (*Geol. Mag.*, Decade VI, vol. i, 1914, p. 529), in his paper on "The Lateritic Deposits of Mozambique," makes the following observations :—

(1) Bauxite on granite, laterite on basic rocks.
(2) Laterite associated with the sides of streams.
(3) No laterite with heavy forest or undergrowth.
(4) No laterite on steep slopes.
(5) No laterite near marshy ground or swamps.

He agrees that wet and dry periods must alternate.

The opinions of W. G. Woolnough as regards the formation of laterite in Western Australia, and of the late Sir John Harrison in connection with the bauxites of British Guiana are similar. They consider that the laterite or bauxite represents a peculiar sub-aerial weathering product of various types of aluminous rocks in Australia and largely diabase in British Guiana. Woolnough (*Geol. Mag.*, Decade VI, vol. v, 1918, p. 385), who records the existence of a kaolin horizon below the laterite, draws the following conclusions :—

(1) If the lateritised rock was a granite the laterite will be aluminous (bauxite); if the rock was a basic variety the product will be ferruginous.

(2) Laterite is formed by the leaching of sub-soil salts during seasons of heavy rain and capillary action to the surface in intervening dry spells.

(3) Laterite only occurs where drainage is almost at a standstill, *i.e.* on low-level peneplains.

(4) High-level laterite indicates elevation of the land.

(5) Difference of laterite level may be taken as evidence of faulting.

(6) Physiographical differences of opinion can be reconciled by the recognition of the essentially low-level nature of laterite.

Now, if these several views, especially the paper by Morrow-Campbell, are carefully studied in the original writings, it will be found that those observers who had examined a wide field have almost identical facts to record, while those whose observations were restricted to exposures in a prescribed area have advanced the more divergent theories. But running through the whole series of carefully written papers on this subject, there emerges overwhelming evidence of the existence of at least two distinct families of bauxite: (B) one is evidently a residual weathering product which lies where it was formed—it represents the greater part of a rock which has been transformed by the leaching out of all its constituents except alumina and ferric oxide; the other (A) is a mud consisting of the hydroxides of alumina and ferric iron, which is left behind as a residue after a large mass of certain kinds of limestones are removed in solution. In both cases the original rocks were evidently exposed to atmospheric weathering. The ground appears to have been elevated with gently sloping surfaces. Rock decomposition was in each case characterised by active chemical corrosion of the rock-minerals and the removal of soluble components. There was an exceedingly small amount of denudation as a result of erosion by abrasive action of running water.

In the first chapter, page 10, I have spoken of the former, normal, or (B) type of bauxite as the laterite type, and referred to the residual mud or (A) kind as the North Mediterranean or terra-rosa type. In the laterite type the residual mass occupies roughly the same volume as that of the rock from which it has resulted. It has an exceedingly porous texture. There has been a great loss of constituents—alkalies, alkaline earths, silica, etc. There has been a considerable addition of water. In the terra-rosa type the residual mud is an exceedingly small fraction of the original mass which has been removed in solution. The texture is fine and impervious. The residual mud may be left on the surface as a mantle of soil, or it may be swept into subterranean cavities.

It is almost unnecessary to say that the primary forms of both families of bauxite—the laterite and terra-rosa types—are liable to mechanical denudation and the formation of detrital or secondary varieties. Nor is it to be forgotten that all the varieties, *i.e.* the primary and secondary varieties of the laterite type as well as the primary and secondary varieties of the terra-rosa type, when once formed, are liable to mechanical displacement or contortion if the regions in which they occur are involved in considerable crustal compression or tension. However, these modifications, due to regional subsidence or elevation by buckling of the earth's crust, will be discussed later.

**Laterite Type of Bauxite.**—During my examination of the lateritic bauxites of India, and later, after visiting the bauxite occurrences in Antrim (Ireland) and the deposits of bauxite in the Var (south of France), I gave the subject of bauxite formation most careful attention. I have carefully scrutinised the literature on bauxite from time to time since, and, notwithstanding all the theories advanced previously by various eminent geologists, I have been led to the conclusion that the conditions necessary for laterite, as distinct from terra-rosa, formation may be expressed as follows :—

(1) A tropical climate subject to alternations of dry and wet seasons or monsoons.

(2) A level, or very gently sloping, elevated land surface which is not subject to appreciable mechanical erosion (abrasion by rain and wind).

(3) The chemical and mineralogical composition of the exposed rocks to be suitable for a supply of the lateritic constituents —alumina and ferric oxide.

(4) The texture of the rock to be (or rapidly become during weathering) sufficiently porous for the entry of percolating water, so that the conditions for chemical action will be at a maximum.

(5) The infiltrating water to remain in the interstices of the rock for long periods annually, *i.e.* during the wet monsoon, but eventually to drain away in the dry period, thus giving maximum play to chemical erosion.

(6) The infiltrating water to contain either an acid or alkaline substance with which to react on the rock components as well as to constitute an electrolyte and allow electrokinetic phenomena to operate.

(7) These annual processes to be in operation continuously for at least a geological epoch of roughly a million years (counting the Miocene *epoch* as of this length of time and the Cretaceous period at five times this amount).

The formation of the hydroxides of aluminium and ferric iron as a product of the weathering of silicate minerals has commonly been regarded as an extreme case of the breaking down of compounds in rock decomposition. It has always been the popular opinion that the silicate minerals first break down into hydrous silicates, and only in the case of lateritisation do the hydrous silicates further decompose into hydroxides of silicon, aluminium, ferric iron, etc.

With the development of colloidal chemistry and the discovery of the colloidal nature of most clays, a new light was thrown on the origin and constitution of clays. However, a disappointingly small amount of work has so far been done with regard to ascertaining the true composition and condition of the colloidal constituents of residual clays. Information is available to show that many clays contain alumina in a soluble form and evidently not in combination with silica, being present in hydrated form as a *gel*. However, it is now thought by many chemists that when rock silicates are subjected to prolonged atmospheric weathering, they break down directly into colloidal hydroxides (hydrosols), and not into hydrous silicates as a first stage. Also, that these substances, the colloid hydroxides, develop electric charges, some positive (usually the bases like ferric oxide and alumina), others negative (like silica hydrosol), with respect to each other, and the electrolyte (alkaline or acid water which is effecting the decomposition of the silicate) in which they are contained (see *Chemistry of Colloids*, by W. W. Taylor, 1915). Further, that these oppositely charged hydrosols, if not in any way protected or separated, mutually precipitate each other, not as amorphous alumino-silicates, but as mixtures of single gels (see " A Short Survey of Physics and Chemistry of Colloids," by Dr. Th. Svedberg, in a publication by the Department of Scientific Industrial Research, London, 1921).

In recent years another aspect of the case, with particular interest regarding a porous decomposed rock mantle, has developed (see papers on " Electro-kinetic Phenomena," in the *Reports on Colloidal Chemistry and its General Industrial Applications*, Department of Scientific and Industrial Research, London : particularly a paper on " Electrical Endosmose," by Dr. T. R. Briggs, 1919, pp. 26-27). Dr. Briggs enumerates four distinct processes. These are as follows :—

(1) When an electrical potential is applied to the opposite sides of a porous diaphragm immersed in an electrolyte, the liquid is forced through the diaphragm with the current. This phenomenon is called *electrical endosmose*. It was applied by Count Schwerin (see *Zeitschrift für Electrochemie*, 9, 1903, p. 739) for the de-watering of peat. The peat acted as the porous diaphragm, and was placed between two metal plates, one, the lower, being a perforated plate. When the plates were connected with a source of electric

potential and the switch closed, water poured from the peat through the perforated plate, which had been made the negative pole or kathode of the circuit.

(2) If the solid, instead of being in the form of a porous diaphragm, exists in a state of suspension, as in a clay "slip," the solid migrates through the liquid to one or other pole of an electric circuit when a current is passed through the "slip." This phenomenon is known as *cataphoresis*. It has been developed in practical form, as the electro-osmosis machine, by Dr. Ormandy, for the purification of clays (see *The British Clayworker*, 1913, p. 9; also paper on "Colloidal Chemistry," by A. B. Searle, p. 113, British Association, Cardiff, 1920).

(3) If as in (1) the solid is fixed in the form of a porous diaphragm, and liquid is forced through its pores in one direction, then a difference of electric potential is developed between the in and out extremes of the diaphragm, and an electric current may be established by connecting these points. This current has been proved, and is known as Quincke's current (see paper by Quincke in *Pogg. Ann.*, 107, 1859, p. 1; and 110, 1860, p. 38).

(4) If the solid, in a finely divided condition, is dropped through the liquid, a difference of electrical potential is established between the upper and lower liquid strata. This is known as Billitzer's experiment (see *Drude's Ann.*, 11, 1903, p. 937).

The above-mentioned phenomena furnish much food for thought in connection with the formation of laterite, particularly with regard to the removal of colloidal silica and hydrous silicates, and the marked separation and segregation of limonite from the bauxite. For example, if a laterite mantle be treated as a porous diaphragm, and the percolating rainwater (carrying nitric or carbonic acid) be considered as the electrolyte, it is evident that electro-kinetic phenomena must occur. The steady downward movement, during the wet monsoon period, of the percolating water, with its discharge from springs along the base of the laterite scarp, will not be the only influence at work tending to separate the soluble and colloidal constituents. In this connection certain peculiarities, shown in Fig. 7, have been observed with regard to the internal structure of a laterite mantle.

The degree of separation into the various constituents shown in the above section (Fig. 7) is in many instances very remarkable. The almost pure pisolitic limonitic covering (or, as Lacroix calls it in West Africa, the *cuirasse de fer*) is abruptly underlain by a rich cream coloured to bluish-grey bauxite, which in turn passes downward into a more and more true lateritic type, richer in silica, etc., until finally, and rather abruptly, at the base there occurs a peculiar, irregularly laminated lithomarge [1] associated with ferruginous layers.

This remarkable separation of ferric hydroxide, alumina, and hydrous silicates of iron (?) and aluminium (see analyses of Katni lithomarge) arrests attention. It would seem that during the rains the leaching action of the rainwater, charged with corrosive acids or salts, as it percolated into and down through the interstices of the rock, and then outward to the springs at the base of the laterite scarps, must carry away all soluble or finely suspended matter. The former would be carried away, but the latter seems to have been deposited as lithomarge. At the close of the rains, and with the coming of the dry weather period, powerful capillary action would be induced, whereby the limonite would be drawn to the surface from the zone a small depth below. The removal of ferruginous matter would thus gradually lead to the formation of a bauxite zone if the

---

[1] “The presence of lithomarge under certain laterites, and evidently intimately related to the overlying laterite, led W. T. Blanford in Orissa (India) to the conclusion that the upper pisolitic ferruginous laterite was detrital, and the lithomarge formed *in situ*. This may probably be correct for Orissa, and may possibly be true for the lithomarge of any occurrence if it is found under and in genetic association with either primary or secondary laterite. As regards the Orissa laterite which is thought to be of the detrital or secondary type, it simply means that this secondary laterite has been recemented (by limonite or silica), and that the processes of lithomarge formation (by downward percolating rain-water) have been re-established. In this connection the following data obtained from a boring are of interest. They show the percentages of *iron* in lithomarge under secondary laterite at various depths. It is most unfortunate that Blanford did not give complete analyses as the lithomarge shows a gradual passage below into gneiss.” (*Mem. Geol. Surv. India,* vol. i, 1859, pp. 273-280, 291.)

| Depth. | Material. | Percentage of Fe. |
|---|---|---|
| 4 feet | Laterite . . | 24·53 |
| 8 ,, | Lithomarge . | 18·71 |
| 12 ,, | ,, . . | 15·30 |
| 16 ,, | ,, . . | 16·11 |
| 20 ,, | ,, . . | 10·00 |
| 24 ,, | ,, . . | 8·37 |
| | *Water level.* | |
| 28 ,, | Clay contains . | 4·80 |
| 32 ,, | ,, ,, . . | 4·08 |
| 36 ,, | ,, ,, . . | 5·34 |
| 40 ,, | ,, ,, . . | 3·85 |
| 48 ,, | ,, ,, . . | 4·47 |
| 57 ,, | ,, ,, . . | 7·16 |
| 64 ,, | ,, ,, . | 5·68 |
| 70·5 ,, | Decomposed gneiss . | 5·67 |

silica has also been removed. However, the removal of the silica cannot thus simply be explained. It seems clear, therefore, that electro-kinetic phenomena must operate, and that the efficiency of the effect is due to the silicate minerals having been broken down completely into component sols and gels (sec pp. 27 and 64, Chapter IV. The steady flow of water (electrolyte) down through the porous mass of decomposed rock, the induced electric-potential difference between the top and bottom of this porous zone of decomposed rock, and the presence of colloidal, electrically-charged particles (sols and gels) supply all the electro-kinetic conditions which are necessary, in addition to the removal by solution and in suspension and upward capillarity already mentioned, for a complete separation of the various constituents. The aluminium hydro-gels will remain practically stationary and function in the porous zone as an impermeable membrane. The positively-charged ferric hydro-gels will be actuated upward both by capillarity and under electrical attraction of the electrical (negative sign) potential of the upper part of the laterite zone. The negatively charged silica, in gel or sol form, will be influenced downward both by the downward current of water and under the electrical draw from the positively charged electrical potential in the lower layer. The neutral hydrous silicate compounds will gravitate in suspension with the relatively rapid downward flow of the percolating water, and be precipitated, where the velocity is greatly reduced, *i.e.* at the base of the laterite mantle. The *modus operandi* seems clear by such an explanation, but the very nature of the process appears to be subject to so many difficulties that it would seem almost a hopeless task to try and obtain experimental evidence in support of such a theory. The several factors, as stated previously, have been verified as in operation in other cases, and have even been utilised with a view to commercial processes ; but as to whether these factors can be proved to be in active operation in laterite formation is still a matter for demonstration. The electrical potentials in the top and bottom of a laterite layer are likely to be so small, and the disturbing influences so large, that it is doubtful if conclusive proof of the existence of such a difference of potential could be established. The greatest factor is time. The processes of rock-decay, the annual leaching of soluble constituents, the migration of sols and gels, and the deposition of suspended particles, are exceedingly slow and maintained for vast periods of time. The exposed sections of laterite that we view show the cumulative result of countless repetitions of small effects, which have steadily operated in the separation and segregation of the chief constituents—the aluminium and ferric iron hydroxides from each other and from the silica which was originally present.

We do not know what complications are present as to changes in the nature of the electrolyte as it gets down into rocks of various types. It is well known that the phenomena of basic exchange occur in some underground waters. It is also well established that the composition of the infiltrating water, before and after it enters the rock, can be different in different areas and depths, *e.g.* percolating water on a bare country will not be contaminated with organic matter as on a well-wooded region, and it is obvious that the presence of pyrite in the rock must affect the composition of the water below ground, and thus modify the simplicity of the electrokinetic action as outlined above. And yet the very fact that the infiltrating water periodically drains almost completely away, leaving the interstitial spaces open to the access of air (in most of the cases where laterite formation is in actual progress), may help to reduce the abnormal factors and make the conditions somewhat general for all examples of laterite formation. Abnormal features, such as composition of the original rock, will be evident in the composition of the resulting laterite, *e.g.* the presence of pyrite, say, in an original shale will possibly accelerate the rate of formation of good bauxite, but leave appreciable traces of sulphur in the bauxite ; on the other hand, an abundance of insoluble constituents, such as titantia in an original basalt, will remain in marked amount as an impurity in the resulting bauxite, and may necessitate the use of the name titaniferous bauxite, as in the case with many Indian bauxites.

**Terra-Rosa Type of Bauxite.**—With regard to the mode of formation of the bauxite deposits of the greater Mediterranean region—Spain, France, Italy, the Adriatic, etc.—and in a similar manner those of the Appalachian area of the United States—North and Mid-West Georgia, Alabama, and Tennessee—the crux of the problem lies in the acceptance of the view that these bauxites are " fossil " terra-rosa muds. The composition of the terra-rosa (or roterde) should show large percentages of aluminium hydroxide and ferric oxide and trifling amounts of silica. This composition of terra-rosa has, so Kerner-Marilaun claims, been already proved by Kispatic. I have been very unfortunate in not seeing convincing analyses of terra-rosa, but I am prepared to believe that the claim has, in some cases, been substantiated. Accepting the view that the residual material or red mud, which is left behind when certain red limestones of Upper Cretaceous (Rudisten-Kalk) and Eocene (Alveoline) age are dissolved in weak acids, is composed essentially of aluminium hydroxide and ferric oxide, then the origin of the " terra-rosa " type of bauxite is self-evident. We can also see very clearly how it has appeared to some observers that the bauxite is a replacement deposit in the limestone. B. Lotti (*Zeits. f. prak. Geol.*, vol. xvi, 1908, p. 501), for example, considered that the bauxite of

Pescosolido (Italy) was of such origin, and was afterwards covered by sedimentary strata.

It must be clearly stated at this point that what is called terra-rosa in these pages is presumed to be a residual clay-like mud which is silica free, and composed largely of the hydroxides of aluminium and ferric iron, or of the hydroxide of aluminium and oxide of ferric iron. Presumably roterde means the same thing, but this must be verified, because I find German writers—Hermann Harrassowitz, *née* H. L. F. Meyer ("Die Bauxitlagerstätten des Vogelsberge," *Metall und Erz,* vol. xviii (N.F. ix), Jahrg. 1921, Heft 22, p. 568)—speaking of the red clay which is associated with the basalt and bauxite of Garbenteich as *rot-erde.* This material would probably be termed bole by English and Indian geologists. The Garbenteich analyses given by Harrassowitz (Meyer) are of interest (see below) :—

| | Basalt. | Bauxite. | Roterde. |
|---|---|---|---|
| $SiO_2$ . . | 52·44 | 3·74 | 25·56 |
| $TiO_2$ . . | 2·09 | 2·73 | 3·08 |
| $Al_2O_3$ . | 14·23 | 51·73 | 32·19 |
| $Fe_2O_3$ . | 2·78 | 14·90 | 19·90 |
| FeO . . | 7·05 | — | 1·83 |
| MgO<br>CaO . | 14·11 | — | 0·60 |
| Alkalies . | 3·90 | — | Traces. |
| $P_2O_5$ . . | 0·13 | ? | 0·29 |
| $H_2O$ . . | 2·53 | 26·58 | 16·64 |
| Totals . | 99·55 | 99·72 | 100·35 |

The high water content of the German (Hesse) bauxite of Garbenteich distinguishes it as possibly being related to the Irish (Antrim) bauxites, and these most probably are of the true laterite type. It must not be forgotten, however, that there are limestones exposed in Antrim of older geological age than the bauxite, and these limestones may have supplied some terra-rosa, as I have defined it, to the lake which at one time is known to have covered part of the lower series of lavas of Antrim. This lake is presumed to have come into being some considerable time after the surface of the lower lavas had been exposed to sub-aerial weathering. Thus it may happen that perhaps both the laterite type of bauxite (in a lower part of the intertrappean horizon) and the terra-rosa type of bauxite (in the upper part of the same intertrappean horizon) may be found in Ireland. Or, what is yet more intriguing, it may be proved, by a very careful study of the Antrim beds, that the laterite type of bauxite may lose some of its contained water if subjected to considerable pressure, due to the weight of superincumbent strata, and thus merge, so far as analyses of composition are concerned, into a terra-rosa facies. However, these are mere guesses, and the same result is possibly also attained when primary laterite is denuded and redeposited as detrital laterite, and suffers dehydration. In this connection the following analyses, quoted by G. C. Dubois, of alluvial laterite from the gold (?) *placer* of Lionaron, near Boschland, Surinam (Dutch Guiana), are elucidating. This material is evidently derived from true primary laterite. The analyses, which were made by Dr. O. Brunck, of Freiburg (Saxony), are as follows :—

| | I | II |
|---|---|---|
| Silica (as quartz) . | About 52 per cent. in each case. | |
| Silica (soluble) . . | 6·03 | 5·68 |
| Alumina . . . | 24·04 | 22·73 |
| Ferric oxide . . | 8·19 | 8·98 |
| Lime . . . | 0·59 | — |
| Magnesia . . . | Traces. | — |
| Water . . . | 9·45 | 10·68 |
| Total . . | 100·26 | 99·99 |

By deducting the quartz, which is largely admixed from extraneous sources, the $Al_2O_3$ becomes roughly 48·00 per cent., the $Fe_2O_3$ 18 per cent., and the $H_2O$ 20 per cent. Even here the water content is too high for what I have called the terra-rosa type of bauxite—such as may be taken from the following analyses of bauxite from (A) Italy, (B) Dalmatia, and (C) Rumania :—

| A (Pescosolido). | | B (from Dernis). | | C (from Cucul). | |
|---|---|---|---|---|---|
| $SiO_2(+TiO_2)$ | 6·87 | $(SiO_2)$ . | ·89 | $(SiO_2)$ . | 1·0 |
| $Al_2O_3$ . . | 56·53 | $Al_2O_3$ . | 51·85 | $Al_2O_3$ . | 56·20 |
| $Fe_2O_3$ . . | 24·88 | $Fe_2O_3$ . | 26·82 | $Fe_2O_3$ . | 29·0 |
| $CaO$ . . | ·25 | $MnO$ . . | 1·21 | $TiO_2$ . . | 2·0 |
| $H_2O$ . . | 11·08 | $H_2O$ . . | 19·97 | $H_2O$ . . | 12·0 |

*N.B.*—The Dalmatian bauxite is probably also a detrital form of the terra-rosa type.

Thus it is seen that the whole problem of relationship depends on, first, obtaining careful analyses as to the true composition of the terra-rosa which is being formed to-day ; second, on ascertaining by experiment if true laterite loses some of its water if subjected to great pressure ; third, to discover if lateritic bauxite loses water if pulverised in water and then allowed to dry in the sun ; and, fourth, to subject terra-rosa bauxite to the same treatment and ascertain whether the dried product has gained in water percentage. It may be taken for granted that, since the lateritic constituents are in the form of colloidals, both the aluminium hydroxide and the ferric hydroxide will be susceptible to reversible transformations from the *sol* condition to that of the *gel*. Thus the *sols* may gelatinate and the material show physical evidence of dehydration, and, *vice versa*, the gels may absorb moisture and solate and the material thus appear to have undergone hydration. These changes would become evident in the above experimental determinations if the drying was not carried above 105° C. Theoretical considerations suggest that the two types of bauxite can be merged into one group, but, as I have pointed out already, we require a good deal more data and analyses regarding this terra-rosa, as being a mixture of the colloidal forms of aluminium hydroxide and ferric oxide, before it will be possible to answer the questions at the head of this paragraph.

It is of some slight interest to discover the possible composition of the red colouring matter of the marine limestones from which the terra-rosa and similar clay-like muds are assumed to be derived as residues. The limestones in question are of upper Cretaceous and Eocene age, and were laid down in the clear, shallow water of warm seas. How, then, came the contaminating red stuff ? The thought which immediately arises is that this red material, so finely distributed in the limestone, is probably similar to the red oceanic ooze or clay which settles as slime over great areas on the floor of the ocean deeps. The volcanic activity and earth movements during the Upper Cretaceous and early Eocene period would possibly have disturbed this red oceanic clay. As a result, it would remain suspended in the water and might then be carried into the shallow seas by ocean currents, and there, in still water, be deposited lightly on or with the limestone. The opinion of Murray and Renard (Challenger Expedition) was that the red clay of the ocean deeps is derived from the decomposition of volcanic ejectament. F. W. Clarke (*Data of Geochemistry*, 1920, pp. 508 and 510) gives an average analysis of this red oceanic clay as (roughly) :—

| | |
|---|---|
| $SiO_2$ | 55·00 per cent. |
| $Al_2O_3$ | 16·00 ,, ,, |
| $Fe_2O_3$ | 8·50 ,, ,, |
| Alkaline earths | 5·00 ,, ,, |
| Alkalies | 5·00 ,, ,, |
| $H_2O$ | 7·00 ,, ,, |
| etc. | 3·50 ,, ,, |

Such a composition would require the elimination of a considerable amount of silica for the red oceanic clay to yield a terra-rosa which might be genetically related to the bauxites of the Mediterranean region. The crux of the question involves the answer as to how the silica is removed from the original contaminating red clay.

Is it removed during the solution of the limestone when exposed to atmospheric weathering, and deposited as the terra-rosa of Kispatic, *i.e.* silica free, or is there a subsequent stage ?

**High Alumina and Diaspore Clays.**—Before closing this chapter on the types of bauxite met with in different countries, and which I have broadly but provisionally classed as belonging to two main types—the Laterite and the " Terra Rosa "—mention must be made of certain high alumina clays which do not appear to strictly belong to either of the types mentioned above. The first case which comes to mind is that of the high alumina clays of Ayrshire, which were, in my opinion, wrongly designated as bauxitic clay. I have expressed my opinion on this material in the review quoted on page 156. A second example of a type of material which does not, owing to its high (80 per cent.) alumina content, low (12 per cent.) combined water percentage, and mode of occurrence, conform to either the laterite or " Terra Rosa " types, although having some features of origin and composition common to both, is the diaspore pisolitic rock of Chakar Salal and Sangar Marg in Jammu, Kashmir. In these cases Mr. D. N. Wadia tells me the pisolitic rock has been clearly derived by the local lateritisation of a clay bed at the base of the Sabathu (Eocene) series, and is not genetically related with the older Great Limestone below (see Fig. 9). Mr. Middlemiss, speaking of the Kashmir bauxites, says : " The deposits get regularly poorer in alumina and richer in silica with depth below the first 4 feet, until simple kaolin is found in nearly all the lower layers." He adds : " This passage downwards from bauxite to kaolin is accompanied by a regular decrease in the specific gravity so long as there is no special development of iron and titania." The following analyses show the remarkable character of the Jammu material :—

| | | | | | |
|---|---|---|---|---|---|
| $SiO_3$ (free) . | 0·25 | 0·30 | 0·50 | 0·40 | 0·50 |
| ,, (comb.) . | 0·45 | 0·95 | 4·03 | 11·88 | 26·20 |
| $Al_2O_3$ . . | 81·12 | 79·85 | 71·40 | 67·54 | 56·14 |
| $Fe_2O_3$ . . | 0·28 | 0·91 | 0·81 | 2·86 | 0·36 |
| $TiO_2$ . . | 3·36 | 3·39 | 8·81 | 2·93 | 2·60 |
| $H_2O$ (comb.) . | 14·45 | 14·50 | 14·25 | 14·15 | 14·00 |
| Specific gravity | 3·20 | 3·08 | 2·99 | 2·93 | 2·70 |
| Locality . . | Salal (Surface) | Chakar (First foot) | Chakar (Second foot) | Sangar Marg | Salal (4 feet deep) |

All the above analyses were carried out by J. and H. S. Pattinson of Newcastle-on-Tyne. These figures have been selected from a large series of analyses which all show the steady increase of the combined silica with depth. As mentioned elsewhere in this book, Mr. Wadia states that the diaspore pisolitic rock passes laterally into clay when traced under overlying strata. These particulars would lead to the conclusion that the portion of the clay bed which has long been exposed to the weather has undergone local lateritisation in the true sense of the word. The relatively low combined water percentage and the very high alumina contents must be due to factors which are dependent on climate, constitution of the clay, and in some way either to the presence of the limestone below or to the coal seam above, or perhaps to both these.

One characteristic of these diaspore beds of Jammu which renders them unattractive, at present, to aluminium manufacturers is their insolubility in caustic soda. This is a peculiar feature when it is remembered that the " white " bauxite from Villeveyrac in France, which is similar in chemical composition but quite different in appearance, and not of so high a specific gravity, does not suffer from this disadvantage. In short, I am compelled to believe that the Jammu material is a true diaspore rock which has formed under laterite-forming conditions from clay of not unusual composition (with specific gravity about 2·54). There is not the slightest doubt that this Jammu material could be marketed after suitable treatment—calcination, etc.—as an abrasive, for refractory purposes, and possibly in the manufacture of high alumina cements. In conjunction with the establishment of a local ceramic industry there might be attempted the manufacture of " mullite " or artificial sillimanite for use in the preparation of Indian-made sparking plugs.

I have not been fortunate enough to obtain full particulars of the diaspore clays of Missouri, U.S.A., the annual production of which is running to 15,000 tons. This substance is almost entirely being employed for refractory purposes, the remainder is used for abrasives. The quantity estimated to lie in the deposits is said to be roughly half a million tons—a not inexhaustible supply. It is presumed that these diaspore clays of Missouri are quite unrelated to the bauxite deposits of north-eastern Mississippi, which are claimed by E. F. Burchard (*Bull.* 750-6, U.S. Geol. Survey, 1925) to be genetically associated with clays containing an appreciable proportion of bentonitic material. The occurrence of siderite with the Mississippi bauxite is thought to lend support to Burchard's theory as glauconite is present under the bentonitic clays. Although the Mississippi data are not applicable to the Missouri material I have found them sufficiently interesting to give some analyses of Mississippi clays and bauxite from Burchard's paper :—

| | | | | |
|---|---|---|---|---|
| $SiO_2$ . | 60·68 | 47·52 | 28·61 | 2·78 |
| $TiO_2$ . | 1·00 | 1·60 | 2·50 | 3·60 |
| $Al_2O_3$ . | 15·66 | 36·18 | 46·27 | 59·58 |
| $Fe_2O_3$ . | 6·40 | 1·08 | 1·46 | 1·72 |
| CaO . | ·29 | Nil. | Nil. | Nil. |
| MgO . | 1·75 | ·07 | Trace. | ·07 |
| $H_2O$ (comb.) | 6·18 | 13·19 | 20·56 | 31·90 |
| „ (moist) | 5·56 | ·36 | ·49 | ·62 |
| | Bentonitic clay from Porter's Creek, Blue Mountain. | Clay with pisolites, Ripley, Tippah County. | Bauxitic clay, Pontotoc County. | Bauxite pisolite, Falkner, Tippah County. |

As regards the siderite, Burchard states : " A specimen of the siderite containing pisolites was analysed in the laboratory of the United States Geological Survey. The specimen was divided into two portions—the fine-grained body of the rock (1) and the pisolites separated from the matrix (2). The analyses indicate that No. 1 is largely a mixture of aluminium hydrate and iron carbonate, and that No. 2 is similar but contains more aluminium hydrate and less iron carbonate." The analyses, by J. G. Fairchild, are given below :—

| | No. 1. | No. 2. |
|---|---|---|
| Silica . . . . | 2·88 | 8·10 |
| Alumina . . . | 27·83 | 38·55 |
| Ferric oxide . . | 1·78 | 3·35 |
| Ferrous oxide . . | 27·58 | 15·29 |
| Titanium dioxide . | 2·00 | 2·80 |
| Manganous oxide . | 1·53 | ·75 |
| Magnesium oxide . | ·77 | ·51 |
| Calcium oxide . . | 1·10 | ·51 |
| Carbon dioxide . . | 19·13 | 10·85 |
| Moisture . . . | Not det. | ·73 |
| Comb. water . . | 15·55 | 19·63 |
| | 100·15 | 101·06 |
| Iron carbonate ($FeCO$) | 44·46 | 24·64 |

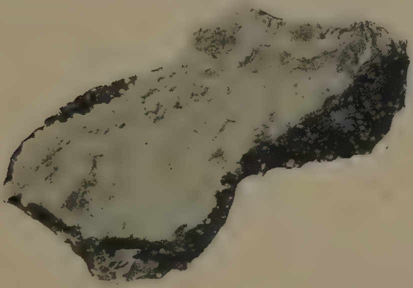
Mr. Burchard considers that these analyses are " suggestive of replacement of the iron carbonate by aluminous minerals." He, however, does not say whether the pisolites had a concentric or uniform internal structure.

True bauxites, as distinct from diaspore clays, which are also present, are said to have been recognised in Greece by G. C. Georgalas, Director of the Greek Geological Bureau (*Echo des Mines*, March 20th, 1924). The bauxites are reported to be red in colour and to average 54 to 57 per cent. $Al_2O_3$, with about 4 per cent. $SiO_2$, while the diaspore deposits carry 72 per cent. $Al_2O_3$. I have not been able to obtain the details of the two types of material.

A certain amount of scientific work has been carried out on the Russian—Tichwinski (Ural)—(diaspore) bauxites. N. S. Kurnakov and G. G. Urazov (*Ann. Inst. Anal. Phys. Chem.*, Leningrad, 1924, 2, pp. 496-498) have found that (1) when a pure kaolin, $Al_2O_3 . 2SiO_2 . nH_2O$ (n about 2), is heated, an endothermic arrest occurs at 558°-605° C. owing to the elimination of water and an exothermic effect (recalescence) at 950°-1000° C.; that (2) under identical conditions the crystalline mono-hydrated alumina, diaspore, shows a temperature arrest at 509°-555° C., but like other hydrated forms of alumina investigated, there is no exothermic effect; and (3) that the natural tri-hydrate of alumina (gibbsite) or artificial trihydrate, is characterised by two endothermic arrests on its heating curve, at 202°-296° C. and about 500°, the latter coinciding with that observed with diaspore. In this connection the following communication, by letter, from the late Sir John Harrison of British Guiana is interesting. He said: "Just before I was invalided home in 1922 I was at work on certain problems in connection with bauxite and kaolin. I found the most reliable mode of determination of whether a hydrated mineral substance or a mixture of such substances was colloidal or otherwise was by very slowly heating in an electric furnace the finely powdered substance and noting the temperature at which it parted with its colloidal or its crystalline or its water of constitution. The colloidal substances gave off their water slowly and continuously, parting with the final fraction of it only at very high temperatures. The crystalline bauxites, including both gibbstite and aluminous laterite, gave off very little water until they arrived at a critical temperature of approximately 250° C. By far the greater portion of the water was given off at this fixed temperature, a thermometer immersed in the powdered substance ceasing to rise until the water had been driven off. Even with these crystalline products some water is retained until a very high temperature is reached. With kaolin-like products the temperature has to be raised to from 600° to 650° C. before water is given off in quantity. There is a check in the rise of temperature at about 625° C. which marks the decomposition of kaolin. In some clays containing halloysite the water of constitution commenced to be evolved about 450° C. With some elaboration I think this method would be of service in determining several problems in connection with the lateritisation and kaolinisation of rocks."

From all that has been represented above, one point is clear, on the basis of Mr. Wadia's evidence, and this is that a clay has, by a process similar to lateritisation, been leached of its silica and that the residue is more aptly described as a pisolitic diaspore material rather than a true aluminous laterite. However, seeing that the subject of the genesis of the French bauxite is not absolutely clear, it is permissible to designate the Jammu material as Kashmir bauxite. In the case of the Missouri rock, I do not know enough to express any opinion. The development of a pisolitic structure can in no way be assumed to indicate whether a material is bauxite or not. A pisolitic structure is common to many substances, *e.g.* the oolitic limestones of England and elsewhere, the pisolitic siderite mentioned above, pisolitic iron ores, typical pisolitic bauxites of the laterite and so-called " terra-rosa " types, pisolitic clays (see Photograph and the analysis given above, and the mention made of such textures in the case of the Ayrshire clays), and, finally, the pisolitic structure of many siliceous products, as, for example, the remarkable rock from Chitorgarh, Rajputana, which could quite easily be mistaken for bauxite (see Photographs VIII and IX).

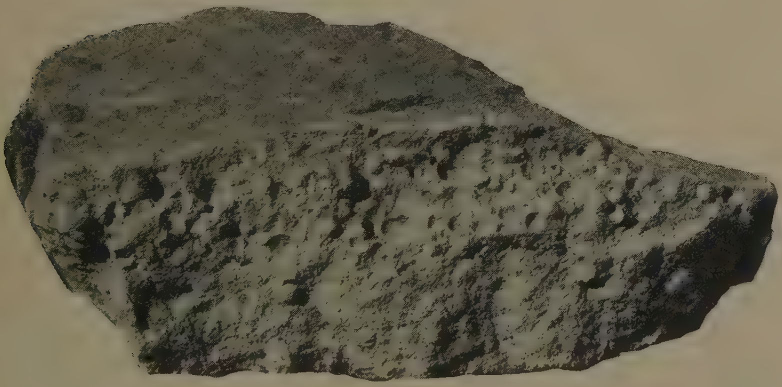
PHOTOGRAPH VIII.



[*C. S. Fox.*

Siliceous Pisolitic Growth on Chalcedonic Geode (India). (Half natural size.)

PHOTOGRAPH IX.



[*C. S. Fox.*

Pisolitic Clay (India). (Half natural size.)

# CHAPTER VI.

## THE BAUXITE OCCURRENCES OF THE WORLD.

BAUXITE has been found in Europe, Asia, Africa, North and South America, and in Australia. These occurrences are either within or not far removed from the tropics. It is also a remarkable fact that, as new deposits are found or old deposits carefully re-examined, the evidence regarding the mode of formation of each deposit favours a similar sub-aerial origin for all laterites and lateritic bauxites. These deposits have evidently been formed in a tropical climate subject to monsoon conditions. The details of lateritisation are discussed in the section on the mode of formation and origin of laterite.

Perhaps the most interesting point in a study of the foreign bauxites, their location, mode of origin, etc., is their age. There seems to be no undoubted laterite or aluminous laterite (bauxite) of pre-Tertiary age. Some of the French bauxites are said to be of Cretaceous age, but by far the greater number of the known deposits were not formed earlier than after the close of Cretaceous times.

Laterites are in process of formation to-day, and may be of any age up to the beginning of the Tertiary era. It would therefore appear that, previous to the Tertiary or Cainozoic period, the wet and dry seasonal phenomenon, known as the Monsoon, had not become an established climatic condition in tropical countries.

There is, of course, another explanation. Previous to Eocene times there were few extensive sheets of basaltic lava in any country. At the close of the Cretaceous period there were great changes in the geography of the early continents, and during this time volcanic action took place on a prodigious scale in America, Africa, Europe, and Asia. In India there are to-day over 200,000 square miles of country covered by the remnants of the lava flows of the Deccan volcanic period, and basalt is pre-eminently the rock from which laterite is formed, when other conditions of climate and topography are suitable.

Further, since laterite is a weathered decomposition product of other rocks, it is evident that the agents of decomposition should be active, and the denudation of the altered rock almost negligible, if appreciable deposits are to be formed. A number of factors play an important part in the formation of laterite: age is the most important factor in the segregation of bauxite. A selective action appears to be operative in all laterites, whereby the aluminous hydroxides concentrate in tubular cavities, nodular secretions, or great, lenticular-shaped bodies of bauxite.

The impurities which are found in laterites and bauxites are important in tracing the original rock from which a primary or *in situ* laterite has been formed, or in proving the detrital or secondary origin of the laterite.

The term laterite is recommended for this family (the laterite-bauxite family) of metamorphic rocks. The word bauxite is preferably applied to those rich aluminous varieties of this rock which form deposits suitable for commercial development.

## AFRICA.

There is an extensive literature dealing with the occurrence of laterite in various parts of Africa—particularly the hinterlands of the Gulf of Guinea and the Atlantic seaboard in this vicinity—from Senegal Gambia through French Guinea and Niger territory across the Gold Coast and Togoland and Nigeria to the Cameroons, and on to the French Congo. Inland laterite was noted by Sir Henry H. Hayden in the Katanga district of the Belgian Congo. Laterite occurs in Rhodesia, the Transvaal, Mozambique, the Nyassaland Protectorate, Tanganyika Territory, Kenya, Uganda, Somaliland, and the Sudan. The islands off the African coast frequently have occurrences of laterite as surface cappings to the hills or plateaux, *e.g.* as in Madagascar, the Seychelles, and elsewhere.

In the majority of cases the record of the existence of laterite dates back into the last century, when it was not known that bauxite was a highly aluminous (pale-coloured) variety of laterite. Recently many of these regions have been re-examined, and as a result reports are steadily accumulating to show that bauxite is of widespread occurrence in Africa.

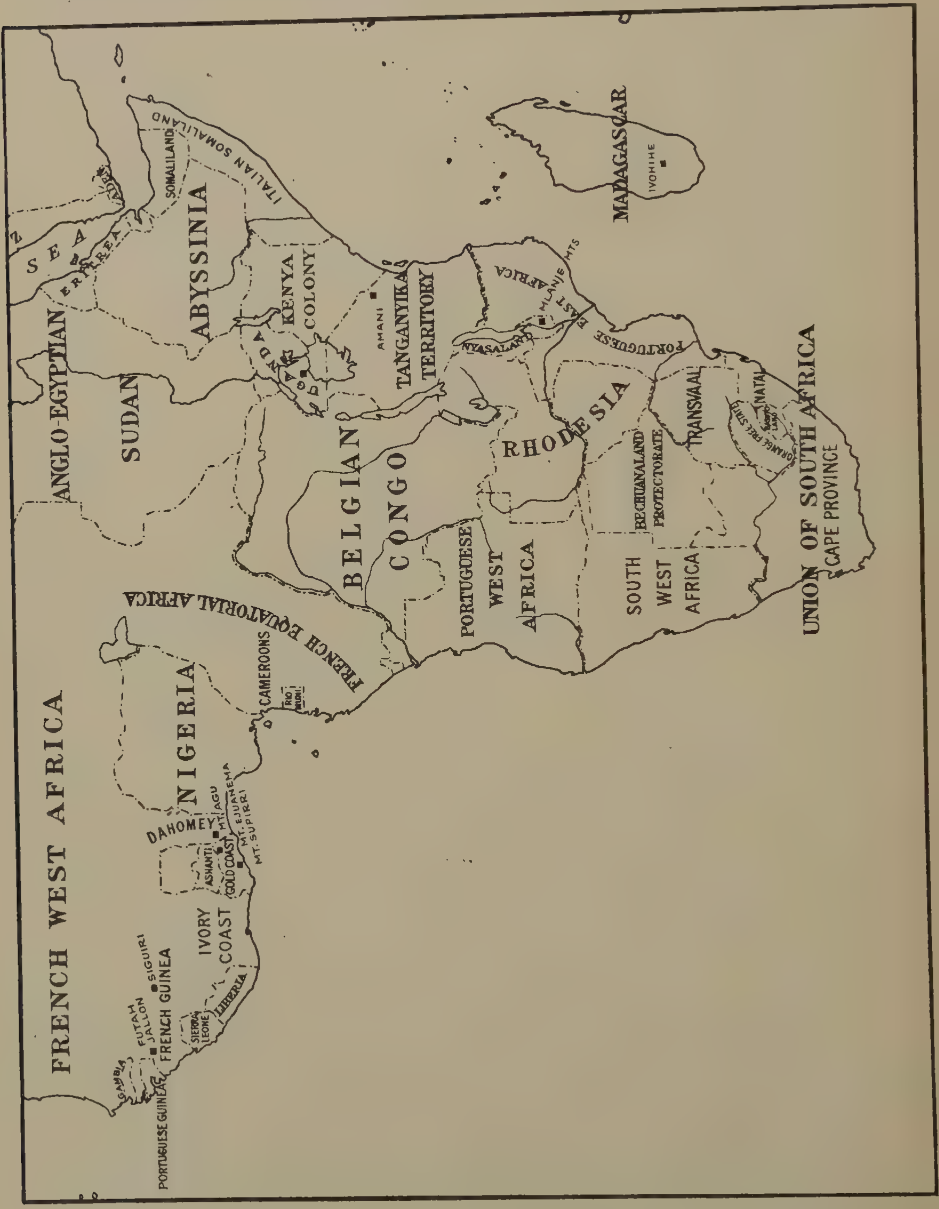
### WEST AFRICA.

**Cape Verde Islands.**—Laterite is reported from here in a paper by C. Doelter.

**Senegal Gambia.**—Occurrence of laterite at St. Louis (16° 10′ N.: 16° 30′ W.) is noted by Lacroix.

**Fernando Po.**—On this island in the Gulf of Guinea laterite has been recorded by Baumann.

**Futah Jallon and Nigeria.**—Clapperton records laterite from Nigeria. Lacroix has explored the coast of Futah Jallon after an examination of the Los Islands near Konalry (9° 30′ N. : 13° 45′ W.). He then travelled inland in an east-north-east direction, arriving at Siguiri or Sigiri (11° 22′ N. : 8° 57′ W.) on the Niger River. He



MAP I.

came south to Kankan (10° 20′ N. : 9° 10′ W.), crossed eastward to Kussan (10° 25′ N. : 7° 25′ W.) through Samory's Empire, and marching south-east finally arrived on the Ivory Coast.

This observer made a careful study of the laterite he met with, and brought away a collection, of which a certain number have been analysed; some prove to be rich aluminous laterite (or bauxite).

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . . | 51·27 | 5·83 | 1·30 | 9·91 | 35·14 | 2·80 | 2·21 | 6·97 | 14·55 | 6·07 | ·37 | 56·88 |
| $TiO_2$ . . | ·70 | 1·29 | 1·03 | 1·44 | ·70 | — | ·12 | 1·02 | ·9 | ·66 | ·90 | ·29 |
| $Al_2O_3$ . . | 12·36 | 37·03 | 60·19 | 22·41 | 40·08 | 8·7 | 55·83 | 50·62 | 46·31 | 39·79 | 57·12 | 22·60 |
| $Fe_2O_3$ . . | 3·29 | 31·73 | 3·91 | 52·53 | 4·12 | 77·2 | 5·22 | 17·69 | 17·65 | 32·26 | 7·41 | ·97 |
| FeO . . | 6·16 | — | — | — | — | — | — | — | — | — | — | 2·19 |
| CaO . . | 10·66 | ·19 | ·17 | Trace | ·45 | — | ·24 | ·17 | ·19 | ·17 | ·17 | 1·33 |
| MgO . . | 13·26 | ·06 | — | ·43 | ·21 | — | ·19 | — | — | — | — | ·56 |
| $Na_2O$ . . | 1·60 | — | — | — | — | — | ·49 | — | — | — | ·26 | 8·30 |
| $K_2O$ . . | ·41 | — | — | — | — | — | ·27 | — | — | — | ·37 | 5·57 |
| $H_2O$ . . | ·40 | 23·02 | 32·0 | 13·26 | 17·84 | 11·4 | 30·47 | 25·80 | 21·40 | 21·05 | 33·71 | ·98 |
| $P_2O_5$ . . | ·11 | — | — | — | — | — | — | — | — | — | — | ·08 |
| Miscellaneous | — | ·96 | 1·40 | — | 1·46 | — | 5·74 | — | — | — | ·30 | ·26 |

1. Unaltered diabase (dolerite), Bongourou Mountain.
2. Laterite immediately above diabase.
3. Bauxite on surface overlying 2.
4. Alluvial laterite from Tinkisso.
5. Fotabar.
6. Laterite analysed by P. Berthier from the Futah Jallon territory. He noted a trace of chromium.
7. Roume (Zone du depart).
8. Siguiri pisolitic bauxite; this contains 6·23 per cent. free $SiO_2$.
9. From Fotaya; contains 13·33 per cent. free $SiO_2$.
10. Surface cuirass of ferruginous laterite.
11. Compact bauxite from Kassa.
12. Unaltered nepheline syenite, Kassa; this contains ·26 per cent. of chlorine.

All the analyses are by M. Boiteau; they are given by Lacroix in his paper on the laterite of Guinea. This writer makes a classification of various laterites. He is of the opinion that the term should be applied to a rock of a certain chemical composition.

**Sierra Leone.**—Anyone arriving at the port of Freetown will notice the laterite ashore. J. M. Campbell's paper deals with this colony. It is only recently (1921) that an aluminous laterite, said to be a low-grade bauxite, has been discovered near Falaba. It is considered to be the residual weathering product of norite, and overlies decomposed norite in many places. The Sierra Leone Geological Survey have the investigation in hand. An analysis published by the Imperial Institute (see *Monograph on Bauxite and Aluminium*, by W. G. Rumbold, 1925, p. 66) of a sample obtained from a road cutting east of Wilberforce gave :—

| | | |
|---|---|---|
| $SiO_2$ . . . | 9·46 | per cent. |
| $TiO_2$ . . . | ? | |
| $Al_2O_3$ . . . | 51·08 | ,, ,, |
| $Fe_2O_3$ . . . | 14·14 | ,, ,, |
| $H_2O$ . . . | 25·32 | ,, ,, |

Material which, chemically at any rate, is unquestionably low-grade bauxite.

## GOLD COAST.

**Ashanti and British Togoland.**—Although the existence of true laterite in various parts of West Africa bordering the Bight of Biafra and the Atlantic has been known for several years, particularly by the publications of Dr. J. Morrow Campbell and Professor A. Lacroix, it was left to Dr. A. E. Kitson, between 1916 and 1921, to find the bauxites of Ashanti and later those of Togoland.

High-grade bauxite is reported by A. E. Kitson, Director of the Gold Coast Geological Survey, from Mt. Ejuanema, 2530 feet, south-west of Mpraeso (Lat. 6° 30′ N. : Long. 1° 0′ W.) on the Kwahu plateau.

The following analysis is said to be representative of the occurrence :—

| | | |
|---|---|---|
| $SiO_2$ . . . | 1·42 | per cent. |
| $TiO_2$ . . . | 2·21 | ,, ,, |
| $Al_2O_3$ . . . | 60·55 | ,, ,, |
| $Fe_2O_3$ . . . | 9·75 | ,, ,, |
| $CaO$<br>$MgO$ . . . | ·73 | ,, ,, |
| $H_2O$ . . . | 25·59 | ,, ,, |

*N.B.*—Appreciable quantities of $CO_2$ are said to be evolved from the bauxite, and many prospecting pits could not be entered in consequence of this gas. Shales and sandstones overlie the granite of the Kwahu plateau, and the bauxite, 33 feet thick, is evidently associated with the shales.

*Mt. Ejuanema*, on the Kwahu plateau, about 2 miles west-south-west of Mpraeso, in the Birrim district of the Gold Coast. The bauxite (aluminous laterite) appears to have been formed as the result of the weathering of almost horizontal beds of shale which, interbedded with sandstones, overlie the granitic mass of the main plateau. The bauxite, which, of course, covers the surface, is said to be 33 feet thick, of which 12 feet to 19 feet averages good ore, and the estimated quantity of bauxite is from 3 to 4 million tons. A peculiar feature of this deposit is that the prospecting pits were found to contain carbonic acid gas ($CO_2$), which is given off from the bauxite. Although this deposit is some distance from the coast, a railway is in course of erection through Mpraeso inland to Coomassi and this line will pass almost at the foot of Mt. Ejuanema. There should be no difficulty in building a shute and bin, or in erecting an aerial ropeway from the bauxite quarries on the mountain to a siding below.

Typical analyses of the Mt. Ejuanema bauxite are given in the accompanying table.

*Mt. Supirri* is the largest bauxite-capped mass in the chain of hills near Sefwai-Bekwai, and lies in the property of the Affoh Gold Mining Concessions. The underlying strata are steeply inclined phyllites and fine mica schists with quartz veins. There seems to be no doubt that the lateritisation of these rocks has produced the overlying residual material—bauxite or aluminous laterite. This mode of origin is amply confirmed by the presence of gold and silver, from the original quartz veins, in the aluminous laterite. Incidentally, the market value of bauxite from this locality will be enhanced by the gold and silver content of the ore, which may go some way to meeting the heavy freight charges from so isolated a locality.

The capping is said to vary from 90 to 50 and 30 feet in thickness. The quality of the material is shown in the table of analyses shown below. The latest estimate of quantity is given by Dr. Kitson as roughly 50 million tons—a very attractive deposit indeed, remembering the gold content and the presence of several other laterite-capped hills in the vicinity of Mt. Supirri.

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $SiO_2$ . . . | 1·72 | 1·78 | 1·22 | 0·62 | 0·60 | 1·42 |
| $TiO_2$ . . . | 1·89 | 1·83 | 2·58 | 1·66 | 0·92 | 2·21 |
| $Al_2O_3$ . . . | 64·40 | 67·52 | 60·71 | 59·05 | 58·26 | 60·55 |
| $Fe_2O_3$ . . . | 2·27 | 3·88 | 9·38 | 12·19 | 8·12 | 9·75 |
| CaO and MgO . | — | — | — | — | — | 0·73 |
| VO . . . | — | — | — | — | — | 0·03 |
| $H_2O$ . . . | 29·24 | 24·84 | 24·93 | 26·47 | 31·82 | 25·59 |

1 to 4. Mt. Ejuanema.
5. Mt. Supirri.
6. Average of 17 samples from Mt. Ejuanema.

Other occurrences of aluminous laterite said to be of bauxite quality have been found in the Assini and Kibbi districts, and in

Eastern Akim, also in the Yenshin district to the west of Coomassie. The laterite capping of Mt. Kawkawti, near Akwadrum, although largely ferruginous, is thought to contain segregations of bauxite. This list of occurrences, however, does not exhaust the possibilities of the Gold Coast, and as the discoveries stand, the known bauxite resources estimated, say, at 60 million tons, constitute almost a hundred years' supply for the present annual demand for bauxite by all countries.

**Togoland.**—There are papers, discussing the question of laterite in this territory, by Henrici, von Francois, Klement, and W. Junkers.

**Dahomey.**—Bauxite had been located on Mt. Agu, 12 miles east of Misahöhe several years ago (1918). The mountain (3400 feet) is largely composed of amphibolite rocks which have been traversed by tongues and sheets of muscovite pegmatite. Kitson considers some of the bauxite as being of good quality, and as occurring in workable quantity.

**Cameroon (Kamerun).**—Weissenborn discusses an occurrence of laterite in the Batanga country (5° 15′ N. : 9° 10′ E.), and G. Zenker records the same substance from Yaunde station (3° 50′ N. : 11° 45′ E.). There are numerous papers by other writers—Rinne, S. Passarge, Morgan, Knockenhauer, Guillemain, Dusen, and F. Wohltmann. No analyses are available, and the area has obviously not been searched for bauxite. C. Guillemain is one of the latest writers, and goes into great detail, but unfortunately no map of the country and no chemical analyses accompany the paper.

**Congo.**—Dupouts, Stuhlmann, and Schweinfurth have recorded laterite from the Congo coastal region.

**Angola.**—Monteiro mentions Loanda (8° 45′ S. : 13° E.) and Benguella (12° 30′ S. : 13° E.) ; the material there would appear to be more typically red clay, but details of its composition are not available.

**French Congo.**—There are papers by Pechuel-Loesche, Buchner, Dupouts, Klement, and Monteiro on this area. The localities discussed are about Gabun (0° 30′ N. : 9° 30′ E.), Loango (4° 40′ S. : 11° 45′ E.), and the Congo State of the same name to the south. There is a partial analysis of the Gabun laterite which shows it to be of the ferruginous variety. It is possible that explorers might collect the ferruginous varieties instead of the pink or grey types, as being more typical of true laterite.

**Sudan and French Congo.**—H. M. Arsandaux has discussed occurrences of laterite in these areas.

### SOUTH AFRICA (RHODESIA, TRANSVAAL, NYASSALAND).

**Rhodesia.**—Although laterite is conspicuously present in Rhodesia, and has been found as a surface mantle in association with almost all types of rock—basalts, granites, etc.—yet no detailed analyses appear to have discovered a true aluminous laterite of a bauxite quality (see E. P. Mennel, *Geol. Mag.*, Dec. V, vol. vi, 1909, p. 350, "Laterite in Rhodesia").

**Transvaal.**—Our information with regard to the Transvaal and the country to the south generally does not disclose the presence of any known occurrence of bauxite. Investigations are being carried steadily forward with regard to the general geology and mineral survey of the Union, so that should bauxite occur in workable deposits, their discovery will be a matter of time.

**Nyassaland.**—In the October (1925) number of *The Mining Magazine* there is a valuable article by Dr. F. Dixey, Geological Survey of Nyassaland, on the bauxite deposits in Nyassaland. He says: "The occurrence of deposits of bauxite on the Mlanje mountains was first recognised by the Geological Survey in September, 1924, during a brief visit to Lichenya Plateau. . . ." The "Lichenya Plateau, like most of the Mlanje plateaux, stands at an elevation of rather more than 6000 feet. . . ." The principal deposit of bauxite occurs on Lichenya Plateau itself, and extends over an area of not less than 2 square miles; over much of this area the deposit ranges from 15 to 30 feet in depth, and in several places depths exceeding 40 feet have been proved. If an average depth of only 7 feet of workable ore be assumed, this deposit contains not less than 20,000,000 tons of bauxite. . . ." "The deposit is overlain by only a few inches of black soil, while it is underlain by fresh or but slightly decomposed syenite." The deposits have been prospected by eight trial shafts 14 to 41 feet deep, and it has been ascertained that the bauxite thickens when followed down the stream which traverses the Lichenya Plateau. As exposed at the surface of the ground the ore forms hard, platey, porous masses that vary in colour from buff to brick-red. At a depth of 1 or 2 feet it becomes fairly soft, so that it can easily be excavated with a hoe. . . . Two samples of the hard porous ore taken from the surface near the Forester's cottage gave the following results upon analysis:—

| | Per Cent. | Per Cent. |
|---|---|---|
| Alumina | 62·08 | 59·80 |
| Iron oxide | 4·00 | 7·00 |
| Silica | 1·21 | 1·70 |
| Water | 31·96 | 30·54 |
| Unestimated | 0·75 | 0·96 |

Subsequently, a sample representing the ore exposed in shafts 1 to 6 at a depth of 6 feet was submitted for analysis, and gave the following result:—

| | |
|---|---|
| Alumina | 57·63 per cent. |
| Iron oxide | 10·35 „ |
| Silica | 1·70 „ |
| Water | 29·92 „ |
| Unestimated | 0·40 „ |

"The foot of the mountains is about 15 miles by road from the Shire Highlands Railway at Luchenza station, which is nearly 330 miles from the port of Beira. A road for vehicular traffic from Lichenya Plateau down to the plain could only be constructed at excessive cost, and consequently some form of aerial cable transport would appear to offer the best means of communication."

It is evident from the above extracts, assuming no serious over-estimate of quantity has been made, that a very valuable occurrence of bauxite has been located in South Africa.

## East Africa (British Areas): Tanganyika Territory, Kenya, and Uganda.

**Tanganyika Territory.**—Laterite was reported from this region over fifty years ago, and J. Thomson specially mentions Usambara. H. Süssenguth made an analysis of material from near Amani in East Usambara (see (1) in table below), and a recent analysis (2) from the same place gives almost identical results. Other analyses —(3) and (4)—of material from about 2 miles west of Mombo, said to be the weathering products of garnetiferous gneisses, are of interest. The Amani material is undoubtedly aluminous laterite, possibly bauxite, but the Mombo samples are either aluminous clays or a mixture of clay and bauxite.

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ | 10·62 | 10·53 | 43·0 | 26·00 |
| $TiO_2$ | — | 1·66 | — | — |
| $Al_2O_3$ | 54·24 | 57·72 | 33·00 | 35·00 |
| $Fe_2O_3$ | 4·26 | 1·15 | ? | ? |
| $Na_2O$ | 1·36 | — | — | — |
| $K_2O$ | 0·78 | — | — | — |
| $P_2O_5$ | 0·04 | — | — | — |
| $H_2O$ | 27·94 | 26·80 | — | — |

Amani occurs only 50 miles from the coastal town of Tanga, on the railway between Tanga and the inland town of Moshi. However, no stir seems to have been created with regard to the Amani bauxite, which would seem to be very suitable for certain chemical purposes, *e.g.* the manufacture of alum and aluminium sulphate. If the Mombo material is a true lithomarge and exceedingly low in ferric oxide, it would be available for numerous purposes, *e.g.* pottery, earthenware, as a filler for paper, etc. (For geological details, see J. Thomson, "Geology of Usambara," *Proc. Roy. Geog. Soc.*, vol. i, 1879, p. 558; also, *Final Report with Guide Map, Geol. Survey, Tanganyika*, 1922, pp. 12-13; also, *The Rift Valley and Geology of East Africa*, by J. W. Gregory.)

**Kenya.**—Although Meyer and Shearson-Hyland noted the occurrence of laterite in their marches to and from Kilima Njaro, and J. W. Gregory speaks as though it were certain that with further geological examination bauxite in workable deposits will be discovered, yet there is no report of such a discovery.

**Uganda.**—There is more definite information of the occurrence of aluminous laterite in various parts of Uganda, including the specifically mentioned locality Bugunda. However, the matter appears to be receiving attention, and it is likely that bauxite occurrences of an attractive character will be discovered before long, both in this Protectorate and in Kenya Colony. (For available data, see *Ann. Rept. Geol. Dept. Uganda Protectorate*, 1920, p. 54.)

## NORTH AFRICA.

**Sudan and Egypt.**—Judging by the specimens on view in the Sudan stall at the British Empire Exhibition (1925), Wembley, there is little doubt that ferruginous laterite exists in the Sudan, but as the specimens were not labelled, it is not possible to specify the locality. However, the evidence, so far as it has been possible to piece it together, points to the probable existence of bauxite in association with laterite in Abyssinia, rather than in the Sudan.

**Algiers.**—An analysis of laterite from this area has been used by Lachmann for comparison with the Rumanian (Hungarian) bauxite. No reference is given to the occurrence, and no more definite locality is mentioned than Algiers.

| | |
|---|---|
| $SiO_2$ | 6·18 per cent. |
| $TiO_2$ | 4·12 „ „ |
| $Al_2O_3$ | 54·33 „ „ |
| $Fe_2O_3$ | 21·74 „ „ |
| $H_2O$ | 12·0 „ „ |

## INDIAN OCEAN.

**Madagascar.**—Two areas are spoken of by Max Bauer in connection with laterite and bauxite. Both are on the eastern side of the island. In the north, ferruginous bauxite overlies diabase (altered dolerite) at Nossi Braha in the small island of St. Marie. In the south bauxite is found overlying granite between Ivohibe and Ikongo (lat. 22° 30′ S.: long. 47° 30′ E.). The age of the deposits is not suggested, but there is no evidence to show that it is not of the Tertiary period. (See also a paper by T. Schlössing.)

The economic aspects of the bauxite occurrences in Madagascar do not appear to have been made public.

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ | 6·68 | 14·70 | 4·61 | 1·34 |
| $TiO_2$ | — | — | — | — |
| $Fe_2O_3$ | 30·80 | 17·97 | 1·00 | 1·03 |
| $Al_2O_3$ | 37·00 | 46·53 | 60·86 | 63·02 |
| CaO | — | — | — | — |
| MgO | — | — | — | — |
| $H_2O$ | 25·52 | 20·80 | 33·42 | 34·61 |

1 and 2. Laterite and bauxite from St. Marie (Bauer). The underlying rock is diabase. Analyses by C. Busz.
3 and 4. Bauxite from Ivohibe (Bauer). Analyses by C. Busz.

**Seychelles.**—Max Bauer examined the laterite of these islands, and from analyses of the rocks definitely proved that certain highly aluminous varieties of laterite were identical with the so-called mineral bauxite. He showed that both granite and diorite were capable of being converted into laterite under the weathering conditions existing in these islands. Unfortunately, he did not discuss the extent and resources of these islands regarding the possibility of using the bauxite. This matter is now receiving attention.

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ | — | 3·88 | 25·80 |
| $Al_2O_3$ | 60·68 | 49·89 | 54·06 |
| $Fe_2O_3$ | 9·56 | 20·11 | 3·12 |
| CaO | — | Trace. | ·56 |
| MgO | — | — | Trace. |
| $H_2O$ | 29·76 | 25·98 | 16·42 |

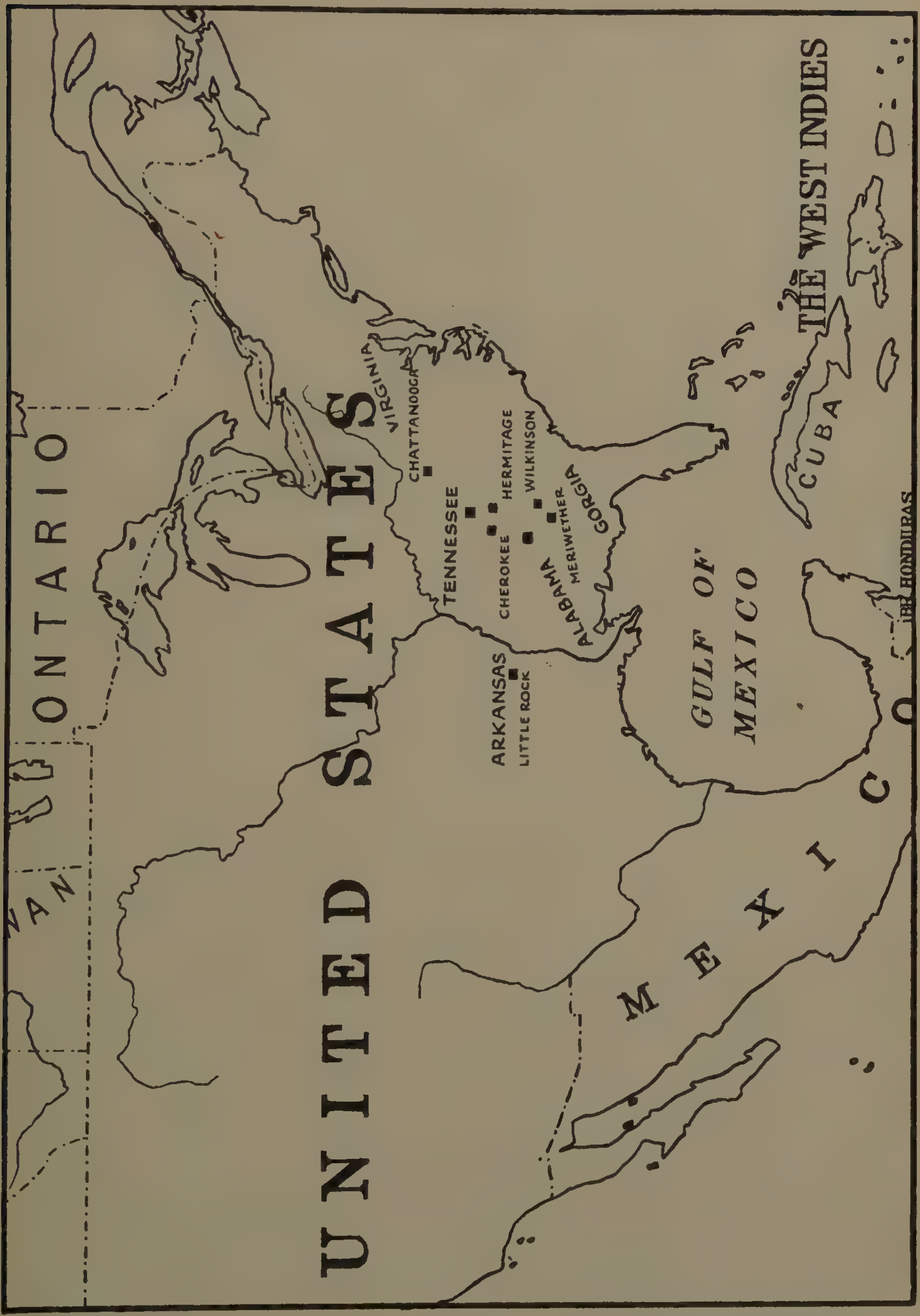
1. Aluminous bauxite or laterite (from granite). Mahé. (C. Busz.)
2. Laterite (from diorite). Mahé. (C. Busz.)
3. Lithomargic bauxite or laterite, overlying granite. Fregatlen. (C. Busz.)

## AMERICA.

### UNITED STATES OF AMERICA.

Bauxite deposits occur in the States of Alabama, Arkansas, Georgia, and Tennessee. (Alunite is reported from California, Colorado, Nevada, New Mexico, Utah, and Virginia.)

Various complicated theories have been advanced to account for the deposits of bauxite. With increasing exposures and recent investigations, however, it appears that the best evidence points to these aluminous concentrations as marking the physical "break" between the close of the Cretaceous period and the beginning of



MAP II.

the Tertiary epoch. At that time the south-east of the United States of America was dry land with a tropical climate, and evidently subject to monsoon conditions.

Bauxite was first discovered in America in 1887, when the material was recognised in Georgia.

Subsequent investigation and exploitation has proved the occurrence of bauxite in several counties—Alabama, Arkansas, Georgia, Mississippi, and Tennessee—in the United States. No bauxite has been found in Canada; in fact, no bauxite has been discovered north of the Fortieth Parallel. The North American occurrences of bauxite of economic value have recently been discussed in a general way by R. B. Ladoo ("Bauxite—Occurrence, Mining, and Uses," *Eng. and Min. Jour. Press*, vol. 114, pp. 805-808, 1922). James M. Hill ("Bauxite and Aluminium in 1916") says:

> All the bauxite mined in the United States is closely associated with kaolin. In the Arkansas field the kaolin is derived from the alteration of syenite in place. In the Tennessee and North Georgia-Alabama fields the origin of the kaolin is not so clear, but it has been formed along faults possibly by the action of circulating waters on limestone, shale, and quartzitic rocks. In the Central Georgia field the sedimentary kaolins are widespread, and were laid down by Cretaceous and Tertiary streams which obtained the materials they carried from the deeply weathered rocks of the Piedmont region.

In *Bauxite and Aluminium in* 1918 (in which a bibliography and map are given), J. M. Hill says:—

> The bauxite from all localities in the United States, though it may vary in chemical composition, is on the whole similar in general appearance, with the exception of the "granitic bauxite" of the Arkansas field. The greater part of the American bauxite appears to be made up of rounded pebble-like bodies set in a fine-grained matrix, which may also consist of small rounded particles, or may be as fine-grained as the finest clay. The pebble or pisolitic form is so general that it is the conspicuous characteristic of American bauxite.
>
> ✓ There is only one way to determine the value of bauxite, and that is by chemical analysis, which should show total silica, alumina, titanium oxide, iron oxide, and water. Bauxites of commercial grade should carry at least 52 per cent. of alumina.
>
> Some measure of the relative quality of dried bauxite can be had by grinding a sample in an agate mortar for half a minute. A bauxite of good grade will be found hard to grind, and will stick to the mortar with such tenacity that it will have to be scoured out; a poor bauxite or bauxitic clay will grind much more easily, and will stick very little, if at all; and clay or kaolin grinds with ease, and does not stick to the mortar. Similar results are found if the sample is rubbed on glass; the glass will not be scratched by even high-grade bauxite.

Although there are several companies engaged in mining bauxite in the United States, the majority of them are subsidiaries to the Aluminium Company of America, the sole producers of aluminium in America. The reason is not far to seek. Of the total production of bauxite in the States, over 70 per cent. is used in the extraction of aluminium, about 20 per cent. is utilised in the manufacture of chemicals, 8 per cent. is absorbed in the preparation of abrasives, and the remainder for various purposes, chiefly aluminous refractories. Thus it is evident that sales of bauxite of a grade suitable for the production of aluminium must depend on the demands of the Aluminium Company of America.

In spite of the fact that new discoveries of bauxite have been made in the States, there has been considerable apprehension that the domestic high-grade bauxite mines will not last another twenty years at the present rate of consumption. A great deal of attention is being devoted to the development of processes, such as the Everhart, for improving the quality of the low-grade bauxites, with a view to utilising this product in the preparation of alumina and aluminium salts, and thus increase the life of the high-grade mines.

**Alabama.**—Bauxite deposits occur, and have been worked, in Calhoun, Cherokee, De Kalb, and Talladega counties (see papers by C. W. Hayes and H. McCalley). However, the deposits appear to have become unattractive, as the operations of several companies seem to have been suspended. The Republic Mining and Manufacturing Company are evidently the most active producers in this State, operating chiefly at Rock Run in Cherokee County. The E. I. du Pont de Nemours Company are said to have given up all idea of continuing their output from the Snider mine north of Piedmont, while there has been no production by the Consolidated Mining Company from De Kalb County for some time. Recently a considerable amount of prospecting has been done in the Enfaula district, the area between Fort Gaines and Clayton, in Henry and Barbour counties, on a westward continuation of the kaolin-bauxite belt of the Coastal Plain. In 1921, J. W. Adams, of Tuscumbia, Ala., while prospecting for clays in Alabama, discovered bauxite near Margerum, Colbert County. These deposits are in erosion channels and sink holes in Mississippian limestone that have been partly filled by Cretaceous gravel. His work led him to suspect the occurrence of bauxite in the State of Mississippi, and after careful search in the field, and a study of a remarkable description in an early report [1] (1860) by E. W. Hilgard, regarding the geology and agriculture of the State of Mississippi, he found bauxite near Blue Mountain, Tippah County. H. McCalley gives the following analyses of bauxite from Rock Run, Cherokee County :—

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $SiO_2$ . . . | 2·90 | 2·10 | 2·10 | ·40 | 8·99 | 4·52 |
| $TiO_2$ . . | 3·40 | — | 3·12 | — | — | — |
| $Al_2O_3$ . | 58·21 | 61·68 | 61·00 | 61·87 | 40·93 | 53·87 |
| $Fe_2O_3$ . | 3·60 | 1·20 | 2·20 | 2·38 | 22·60 | 8·16 |
| $H_2O$ . . | 31·89 | 31·45 | 31·58 | 30·50 | 20·43 | 24·86 |
| Colour . | White. | White. | White. | White. | Red. | Red. |

---

[1] Bauxite was not known to occur in the United States until 1887, when it was recognised in Georgia.

The white bauxite, with its low ferric oxide content, is particularly useful for the manufacture of alum, and has almost entirely been used for this purpose.

**Arkansas.**—Bauxite has been worked for many years in this State in the vicinity of Little Rock, in Saline and Pulaski Counties. Bauxite (5 miles east of Benton), in Bryant District, Saline County, lies 22 miles south-west of Little Rock. The Fourche Mountain District, Pulaski County, lies immediately south of the city limits of Little Rock. The deposits have been described by W. F. Berger, J. C. Branner, J. F. Williams, C. W. Hayes, W. S. Mead, and C. K. Leith. The two last-named writers find that this bauxite is clearly the surface weathering product of local nepheline syenite. From his description, it seems evident that the Arkansas bauxite is very similar in mode of origin to the aluminous laterite of India.

In spite of a " severance " tax of 25 cents per ton (imposed by the Arkansas Legislature in 1923 on all bauxite mined in the State), the output of bauxite by five companies in 1923 was 493,880 (long) tons, *i.e.* an increase of 85 per cent. over the production of the previous year. However, the imports of increasing quantities of bauxite from South America show that there is a considerable domestic demand for bauxite. Owing to a considerable (100 feet) thickness of overburden, the American Bauxite Company have been forced to give up their steam shovel quarrying method of stripping the overburden, etc., and take to mining. Drainage and haulage tunnels have already been driven, and a retreating caving system similar to that used in mining gently inclined seams of coal is to be adopted. This company built (in 1915) a loading station at Bauxippi, to tranship their bauxite from cars to river boats for transport to the alumina plant at East St. Louis.

The National Bauxite Company and the Southern Bauxite Company of Benton are operating near Little Rock and Bauxite respectively. The Arkansas Bauxite Products Company, of Little Rock, are erecting a 50-ton alum plant at that city, based on supplies of ore from Bauxite, Saline County. The Norton Company, who have large quantities of bauxite in deposits adjoining those of the American Bauxite Company, are said to have in hand the erection of electrical equipment for the manufacture of crude aluminous abrasives and refractories at Bauxite. The Republic Mining and Manufacturing Company and the Globe Bauxite Company operate in Pulaski County.

Branner gives a number of analyses, from which the following are taken to show the types that are worked :—

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ . . . | 2·0 | 10·13 | 3·34 | 4·89 | 48·05 |
| $TiO_2$ . . . | 3·50 | — | — | — | — |
| $Al_2O_3$ . . . | 62·05 | 55·59 | 58·60 | 46·44 | 38·92 |
| $Fe_2O_3$ . . . | 1·66 | 6·08 | 9·11 | 22·15 | 1·19 |
| $H_2O$ . . . | 30·31 | 28·99 | 28·63 | 26·68 | 11·32 |

1. Pink bauxite (No. 7).
2. Light brown bauxite (No. 1).
3. Light red bauxite (No. 3).
4. Brick-red bauxite (No. 4).
5. Pisolitic kaolin containing ·46 per cent. $H_2O$ as moisture, ·58 per cent. CaO, ·45 per cent. MgO, ·28 per cent. $Na_2O$, ·18 per cent. $K_2O$.

W. F. Berger gives an analysis very similar to (1) as being suitable for the manufacture of alum.

It has been estimated that 75 per cent. of the annual output of Arkansas bauxite is purified to alumina for reduction to aluminium, 18 per cent. is utilised for the production of abrasives, 5 per cent. is used in the manufacture of chemicals, and the remainder is made into furnace refractories.

**Georgia.**—Bauxite has been worked at various times in several counties—the most important being Sumter, Macon, Floyd, Wilkinson, Bartow, Randolph, Meriwether, and Halls Counties. Descriptions of the bauxite occurrences in Georgia have been given by S. W. McCallee, T. L. Watson, J. W. Spencer, W. F. Berger, C. W. Hayes, O. Veatch, and recently by T. Poole Maynard (on behalf of the Central of Georgia Railway). It is to be remembered that bauxite was first discovered in America in this State in 1887 (see also Hilgard under Alabama). Since then many deposits have been found in the counties mentioned above, and in many localities the bauxite has been completely extracted. The annual reports, *The Production of Bauxite and Aluminium* (successively until 1915 by W. C. Phalen, and since by James M. Hill), of the U.S. Geological Survey, are most valuable sources of information regarding the earlier companies and deposits, many of which are still operating in the same places. Among these may be mentioned the Republic Mining and Manufacturing Company (who have workings near Andersonville in Sumter County, various mines in the Hermitage district of Floyd County, and in the vicinity of Irwinton in Wilkinson County), the Kalbfleisch Corporation (operating in Macon County and near Springvale, Randolph County); the Ideal Bauxite Company (at Ellaville, Macon County); and the Warner Bauxite Company (Adairsville, Bartow County). The Aluminium Company of America were at one time (1913) interested in the deposits of Booger Hollow, south of Rome, Floyd County. The Cherokee Bauxite Company at one time operated near Hall's Station (Linwood

Post Office), Bartow County. The National Bauxite had interests in the vicinity of Toomsboro, Wilkinson County.

The following analyses are said to be representative of the deposits of the above localities :—

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 2·30 | 10·17 | ·62 | 3·74 | 2·60 | 41·20 |
| $TiO_2$ | 2·00 | 2·30 | 1·05 | 9·70 | 4·32 | 1·95 |
| $Al_2O_3$ | 60·64 | 52·92 | 64·91 | 52·36 | 59·68 | 38·10 |
| $Fe_2O_3$ | 1·33 | 7·66 | ·28 | ·76 | ·23 | 1·45 |
| $H_2O$ | 2·79 | ·35 | ·53 | ·20 | — | ·35 |
| $H_2O$ (combined) | 30·58 | 26·55 | 33·00 | 33·17 | 30·03 | 16·35 |

1 and 2. Wilkinson Co. (S. W. McCallie.)
3 and 4. Floyd Co. (T. L. Watson.)
5. Barton Co.
6. Kaolin, Flowery Bank, Hermitage Dist. (J. W. Spencer.)

This kaolin contains ·80 per cent. free $SiO_2$, ·30 per cent. MgO, ·02 per cent. $Na_2O$, and ·09 per cent. $K_2O$.

The bauxite appears to occur in "pockets" as deposits of lenticular shape, and is generally found in intimate association with beds of kaolin. At Sweetwater Creek, 5 miles east of Andersonville, there is a true bed of bauxite overlaid by clays and sands of sedimentary origin. Roughly, 60 to 90 per cent. of the production is taken by the chemical industry, 30 to 10 per cent. for the manufacture of abrasives, and the remainder for purification to alumina for reduction to aluminium. The annual output is being more and more largely absorbed by chemical companies for the manufacture of alum, etc. It is the practice in Georgia to "dry" the bauxite before despatching it from the mining areas. In 1922, 85 per cent. of the output was sold dried. The associated clays, which are present in large quantities, have been found very satisfactory for the manufacture of refractory bricks.

**Tennessee.**—The bauxite occurrences in this State are evidently related to those of North-East Alabama and North-West Georgia. The best known localities are those in the Chattanooga district, near the east end of the McCallie Avenue tunnel, through (1) Missionary Ridge and at (2) Sherman Heights, and those of (3) Keenburg in Carter County. The Sherman Heights deposit was once actively worked by the Aluminium Company of America, but are now idle. The other two occurrences have changed hands, being first controlled by the National Bauxite Company; they have now evidently been secured by the Kalbfleisch Corporation, and are still worked in a small way. White, McAllister, and Keiser were also working mines on Missionary Ridge in 1922, and the Watanga Mining Company were busy in 1919 near Elizabethon in Carter County. Details of all these deposits are to be found in the annual publications of the U.S. Geological Survey, *The Production of Bauxite and Aluminium.* In the report for 1913, by W. C. Phalen, the following analyses of bauxite from Missionary Ridge are given :—

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Insoluble . . . | 12·13 | 11·15 | 11·33 | 11·07 | 13·12 | 12·65 |
| Alumina ($Al_2O_3$) | 57·56 | 57·63 | 57·37 | 57·83 | 55·11 | 55·50 |
| Iron oxide ($Fe_2O_3$) | 1·34 | 1·18 | 1·10 | 1·10 | 1·38 | 1·34 |
| Loss on ignition . | 28·97 | 30·04 | 30·20 | 30·00 | 30·39 | 30·31 |

From the above analyses it would appear that the Tennessee bauxite, being low in ferric oxide, was excellent material for the manufacture of aluminium sulphate and similar chemicals. G. H. Ashley (" Bauxite Mining in Tennessee " : *Resources of Tennessee*, vol. i, No. 6, pp. 211, 219, 1911) gives a description of the earlier discoveries.

**Virginia State.**—Sterry Hunt records alunite from the Blue Ridge south-west of Lynchburg. No bauxite has been reported from north of the fortieth parallel.

**Mississippi.**—Although no bauxite was shipped from this State in 1923, two years after their discovery by J. W. Adams, yet the occurrences of Blue Mountain, Tippah County, and various other places, are considered as very valuable. E. F. Burchard (*Bull.* 19, Mississippi State Geological Survey), who visited the field in 1923, says that deposits of " bauxite or bauxitic clay " have been located " in Tippah, Benton, Union, Pontotoc, Calhoun, Webster, Oktibbeha, Winston, Noxubee, and Kemper Counties." The Mississippi Bauxite Company has been formed with a view to exploiting the area. The bauxite occurs in deposits in a belt 3 to 5 miles wide, trending in an arc from north to south-east, and form little hillocks 50 to 100 feet above the surrounding drainage level. Many of the deposits have been proved to be from 10 to 15 feet thick, and cover an area of several acres. There are two varieties, hard and soft bauxite, and as a rule, it is of the typical American type, *i.e.* pisolitic. It appears to be somewhat low-grade material, for the alumina averages 35 to 45 per cent. ; the ferric oxide runs from 5 to 35 per cent. ; the silica ranges from 3 to 40 per cent., but is roughly from 10 to 30 per cent. on the average ; the loss on ignition lies usually between 15 and 25 per cent. ; the titania varies from 0·5 to 3·6 per cent. The reserves of the lands leased by the Mississippi Bauxite Company are estimated at 1½ million tons. However, the area is deficient in roads, and much has yet to be done to develop the industry.

**Missouri.**—So far as is known, there are no bauxite occurrences in this State, but there are small but valuable deposits of what are called "diaspore-bearing" clay, carrying more than 50 per cent. alumina. There has been great activity in mining diaspore clays in Franklin, Gasconade, and Osage Counties. The most important deposits are in Central Missouri, in the vicinity of Belle, Rosebud, and Owensville. This material, which appears to fetch from $6 to $8 a ton f.o.b. shipping point, is being produced annually to an amount varying from 12,000 to 20,000 tons. The principal producers are the American Refractories Company, Evens & Howard Fire-brick Company, H. H. Heck Clay Company, and Laclede-Christy Clay Products Company. The whole output is utilised in the manufacture of aluminous refractories, for which purpose this clay appears to be better than bauxite. It has also been used in the manufacture of aluminous chemicals, and in the out-turn of abrasives. The clays of this region have been described by D. C. Wysor (*Am. Ceramic Soc. Jour.*, vol. vi, p. 501, 1923).

**Nevada.**—No bauxite occurs in this State. F. L. Ransome and J. E. Spurr have discussed the occurrence of *Alunite* in the Goldfields area.

**New Mexico.**—There is no bauxite in New Mexico. The confusion of such an impression is due to the occurrence of *Alunogen* in Grant County. These deposits were first described by W. P. Blake, and then in greater detail by C. W. Hayes. This material, essentially an aluminium silicate with large amounts of aluminium sulphate and iron-aluminium sulphate, is not likely to be exploited for some time, owing to its inaccessibility.

**Utah.**—The *Alunite* of Marysvale has been discussed by Butler and Gale. The composition is given as 37·18 per cent. $Al_2O_3$, 38·34 per cent. $SO_3$, 12·90 per cent. $H_2O$, and 10·46 per cent. $K_2O$, with small amounts of $SiO_2$ (·22 per cent.), $Na_2O$ (·33 per cent.), and $P_2O_5$ (·58 per cent.). It is thought that the alumina, which is obtained as a by-product from the potash plants at Marysvale, can compete with bauxite both for chemical and refractory uses. Over 1000 tons of by-product alumina obtained from Marysvale in 1923 have been utilised in the preparation of high-grade aluminous refractories. The Florence Mining and Manufacturing Company, who have large holdings in the Tushar Mountains, have been experimenting with a view to making aluminium sulphate and potash alum directly from alunite, and also to make the by-product alumina suitable for direct reduction to aluminium (see *Salt Lake Min. Rev.*, 30 June, 1923, p. 12; also paper by R. H. Tingley, "Alunite and its Products," in *Eng. and Min. Jour. Press*, vol. 115, p. 494, 1923).

James M. Hill says :—

> Alunite deposits are known to occur in various parts of the United States, and may in the future be the basis of industries in areas where bauxite would not be readily obtainable.

**California.**—A nodular laterite evidently associated with "high alumina" clay, carrying more than 50 per cent. alumina, was discovered by L. M. Richards in Riverside County in 1920. A bed of laterite was recognised in a clay pit of the Stockton Fire Brick Company, north-west of Ione, Amador County, by James M. Hill, in 1923. Although this occurrence is not of commercial importance, it is most interesting. Hill gives the following analyses :—

| | A | B | C |
|---|---|---|---|
| Silica . . . | 29·64 | 33·56 | 38·30 |
| Alumina . . . | 27·90 | 34·72 | 41·50 |
| Ferric oxide . . | 24·30 | 16·14 | 6·00 |
| $H_2O$ (comb.) . . | Not determined. | | 12·60 |
| $H_2O$ (moisture) . | ,, | ,, | 1·50 |

H. W. Turner has recorded the occurrence of alunite from the Indian Gulch area, and gives analyses averaging 38 per cent. alumina, 37 per cent. $SO_3$, 12 per cent. $H_2O$, and 4 per cent. $K_2O$. However, the deposits do not appear to have received much attention.

A large deposit of Andalusite, aluminium silicate, carrying 63 per cent. alumina and 37 per cent. silica, is being quarried (1923) by the Champion Porcelain Company, in the Inyo Range, Inyo County. The raw material has been found very suitable for the manufacture of spark-plug porcelain. Further prospecting operations in the north of the State are said to have led to the discovery of kyanite and sillimanite near Ogilby, but it contains too much lime for refractory purposes.

**California State.**—H. W. Turner records the occurrence of alunite from the Indian Gulch area, and gives the following analyses. (No. 1.) :—

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ . . | 2·64 | 2·82 | ·22 |
| $TiO_2$ . . | ·40 | — | — |
| $Al_2O_3$ . . | 38·05 | 38·91 | 37·18 |
| $Fe_2O_3$ . . | ·23 | — | Trace. |
| CaO . . | ·55 | ·35 | — |
| MgO . . | Trace. | Trace. | — |
| $Na_2O$ . . | 2·78 | 4·32 | ·33 |
| $K_2O$ . . | 4·48 | 4·03 | 10·46 |
| $H_2O$ . . | 11·92 | 13·03 | ·09<br>12·90 |
| $SO_3$ . . | 38·50 | 35·91 | 38·34 |
| $P_2O_5$ . . | — | — | ·58 |

**Colorado State, Rosita Hills.**—W. Cross describes the alteration of rhyolite to quartz-alunite at Democrat Hill, and gives an analysis (No. 2 above).

**Nevada State.**—F. L. Ransome and J. E. Spurr discuss the occurrence of alunite in the Goldfields area region.

**New Mexico State, Gila River.**—Alunite from this State has been described by W. P. Blake and C. W. Hayes.

### CANADA.

Claims have been made as to the occurrence of bauxite in British Columbia, near Stony and Demaniel Creeks, Sooke district of Vancouver Island. The material on analysis averages :—

| | |
|---|---|
| Insolubles, probably $SiO_2$ | 25 to 62 per cent. |
| $TiO_2$ | Nil to trace. |
| $Al_2O_3$ | 30 to 19 per cent. |
| $Fe_2O_3$ | 6 to 30 ,, ,, |

With a combination of the highest alumina and lowest silica percentage, the material would not be laterite, so that the designation bauxite is quite wrong. This material is being marketed for use by gas companies, evidently in scrubbers, for refining gas. (See paper by R. Dunn, "Discovery of Bauxite in British Columbia," *Can. Min. Jour.*, 30 Nov., 1923, p. 947 ; also an article, "British Columbia Bauxite Mined for Use in Refining Gas," *Eng. and Min. Jour. Press*, 1 Dec., 1923, p. 960.)

It is, of course, well known that the aluminium produced at Shawinigan Falls, Quebec, by the Northern Aluminium Company of Canada, is by the reduction of imported alumina from East St. Louis.

### CUBA.

In the Province of Oriente, about Nipe Bay, there are rich ferruginous laterites in the Mayari and Moa districts. These lie in the eastern end of the island, and have been well described by C. K. Leith and W. J. Mead, and also by J. F. Kemp. The underlying rock, at 29 feet from the surface, is serpentine and an altered ultra-basic rock, probably a peridotite.

The presence of all the minor constituents in the serpentine nullify the argument that their occurrence in the laterite is due to an organic source. There is no record of any carbonaceous matter which might be the remains of any organisms through whose activity lateritisation was accomplished.

The deposits are worked as an iron ore. Their origin is proved to be due to that peculiar form of weathering, whereby the silicates are broken up, the silica removed, and chiefly hydroxides of iron and aluminium left, as residues in the form of a crust, on the rock from which they have been derived.

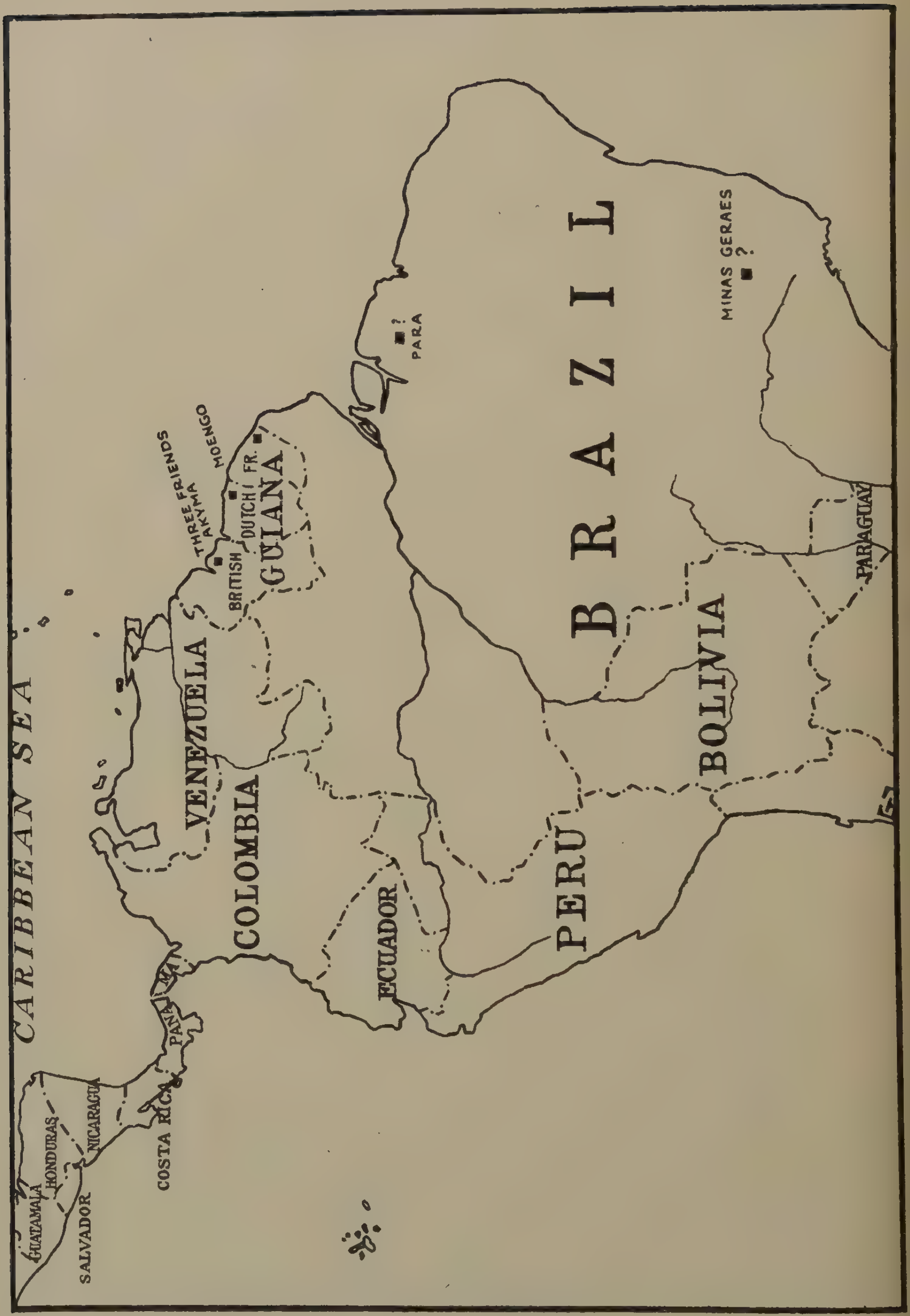
## SOUTH AMERICA.

The occurrence of laterite along the coastal region of South America from the Orinoco to the Amazon has long been known. However, some excitement appears to have resulted from the discovery that much of this laterite was highly aluminous, and easily classed as bauxite of superior quality. The chief bauxite occurrences appear to lie in British Guiana, but excellent material has also been found in Dutch Guiana (Surinam) and in French Guiana. These laterites and bauxites have been shown to be the residual weathering (sub-aerial) of metamorphic rocks—chiefly diabases and hornblende schists in British Guiana. The most important investigations in this connection are those by Sir John Harrison. He is of the opinion that the older and more aluminous laterites occur in positions further away from the shorer lines, *i.e.* on the low rocky country to the south of the coastal strip of alluvium. His work tends to prove that the more seaward laterites, which occur on the alluvium, are due to secondary lateritisation of an *in situ* character, as distinct from an aggregation of detrital lateritic material. He finds, from the boring records for water in the alluvial tracts, that the coastal alluvium appears to overlie deep buried river valleys as though the rocky shore had sunk but been rapidly covered by sediments to such an extent as to keep a more or less stationary shore line. A little further inland it would seem that there is evidence of a gradual rise of the land, which has been in progress for a considerable period. It is quite possible that there have been slow oscillatory movements. The age of the laterite is not definitely known, but it is thought to be not older than early Tertiary.

## BRITISH GUIANA.

The occurrence of workable quantities of bauxite had been ascertained in 1913-14 by investigations conducted under the scrutiny of Sir (then Professor) John Harrison, but it was thought that the supply was not large. Subsequent exploration has shown that the bauxite resources of British Guiana are considerable, both in quality and quantity. Owing to the war and the following trade slump, development was at first slow, but in 1923 exports appear to have been at the rate of 2000 tons a week, and recently the shipments of bauxite have been of the order of 20,000 tons monthly. If this rate of production is maintained, British Guiana will be the second greatest producer of bauxite, and will probably assume a still more important position as regards an output of high-grade bauxite. This fact has been fully grasped by American consumers of bauxite, who find their domestic supplies becoming poorer in quality and nearing exhaustion. The Northern Aluminium Company

MAP III.


CARIBBEAN SEA
GUATAMALA
SALVADOR
HONDURAS
NICARAGUA
COSTA RICA
PANAMA
COLOMBIA
VENEZUELA
ECUADOR
PERU
BOLIVIA
PARAGUAY
BRAZIL
BRITISH
DUTCH
FR.
GUIANA
THREE FRIENDS
AKYMA
MOENGO
PARA
?
MINAS GERAES
?

of Canada, at first in conjunction with the Merrimac Chemical Company of Boston, Mass., who have now dropped out, have secured important concessions in both British and Dutch Guiana, and are at present the chief exporters of this substance. In the Demerara area they operate at Three Friends, fourteen miles above Wismar, on the Demerara River, under the designation of the Demerara Bauxite Company, and have a drying plant at Mackenzie City, opposite Wismar, with private shipping facilities—the Aluminium Line consisting of two steamers of 3000 tons cargo capacity each. (L. T. Emory, "Bauxite Deposits of British Guiana," *Eng. and Min. Jour. Press*, 25 April, 1925.)

In a very detailed report Sir John Harrison has discussed the scientific and economic aspects of the bauxites of British Guiana. He gives the names of several localities in which material of high grade has been found. These are chiefly in the vicinity of the more important rivers or their tributaries, and mainly between the Essequibo River and the borders of Surinam. The more valuable occurrences lie along the banks of the Demerara River from Wismar and Christianburg southward for ten to fourteen miles to Akyma and Komaru.

There is usually an intimate association of kaolin with the bauxite—also a normal feature in respect to the bauxites of India and the United States. Also, there are very large quantities of low and poor-grade bauxite, which may be amenable to purification by the Everhart or other process.

The recently issued *Handbook of British Guiana* contains details of economic interest in connection with the minerals of this colony, and includes an excellent map of the country. On this map, and in the text of the book, one is surprised to discover the presence of so many important waterfalls on the upper reaches of many of the large rivers. The magnificent Kaieteur Falls, on the Potaro River, have a drop of 741 feet, nearly five times the height of Niagara, the width at the top is from 350 to 400 feet, and the depth of water varies from 20 feet to a few feet, according to the season of the year. The presence of these falls show the great hydro-electric power potentialities of British Guiana. It is quite evident that these natural assets of power and material give to British Guiana the means of becoming one of the great world producers of aluminium, abrasives, aluminium salts, and other aluminous products.

A very full report dealing with the bauxite of this colony has been prepared by J. B. Harrison. He mentions a large number of places where it occurs, and gives analyses from Christianburg (lat. 6° 4′ N. : long. 58° 20′ W.), Itumi River (Berbice), Tumatumari (Potaro River), Kumaru (Demerara River), Yarikita River, Issorora and

Essequibo ; most of these localities are near the borders of Surinam (Dutch Guiana).

Harrison's report is full of interesting information. He states that the aluminous laterite is the residual weathering product under sub-aerial conditions, of a diabase, and he gives analyses of the underlying rock at various localities :—

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ (colloidal) | ·14 | — | — | — | — | — | — |
| $SiO_2$ (free) . | ·42 | ·2 | 1·49 | 5·96 | ·02 | ·08 | ·05 |
| $SiO_2$ . . | 2·29 | ·4 | 1·24 | 4·97 | ·31 | 2·12 | ·95 |
| $TiO_2$ . . | 1·07 | 1·3 | ·10 | 5·83 | ·20 | ·60 | 1·10 |
| $Al_2O_3$ . . | 67·28 | 63·6 | 64·38 | 67·28 | 64·73 | 64·70 | 70·90 |
| $Fe_2O_3$ . . | 1·53 | 1·5 | ·50 | ·80 | ·24 | ·90 | ·80 |
| CaO . . | ·02 | — | — | — | — | — | — |
| MgO . . | ·07 | — | — | — | — | — | — |
| $K_2O$ . . | ·08 | — | — | — | — | — | — |
| $H_2O$ . . | 27·46 | 32·8 | 32·29 | 31·81 | 34·49 | 31·60 | 26·20 |
| $P_2O_5$ . . | Trace. | — | — | — | — | — | — |

1. Hard, cream-coloured bauxite, Christianburg. (H.)
2. Itumi River, Berbice (No. 4. 9-11-15). (H.)
3. Yarikita River (hill south of river). (H.)
4. Wismar, Demerara River.
5. Issorora, N.W. district, summit of ridge.
6. Arawaii, Essequibo River.
7. Makauria, " "

Except for No. 4, the above represent bauxites of very good quality indeed. No. 7 shows a certain degree of dehydration. From the fact that these bauxites are the residual products of the lateritisation of basic rocks, it is likely that the time of formation has been considerable.

The following analyses by Harrison are of great interest :—

| | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| | *a* | *b* | *a* | *b* | *a* | *b* | *a* | *b* |
| $SiO_2$ (free) . | 4·30 | 13·77 | 1·60 | 11·98 | ·03 | 7·73 | — | ·30 |
| $SiO_2$ . . | 45·45 | 1·67 | 49·59 | 3·82 | 51·06 | 4·80 | 49·06 | 2·83 |
| $Al_2O_3$ . . | 12·18 | 32·47 | 15·80 | 30·94 | 15·70 | 40·33 | 18·87 | 56·42 |
| $TiO_2$ . . | 4·60 | 4·37 | ·40 | 1·70 | 1·70 | 4·32 | ·88 | 0·83 |
| $Fe_2O_3$ . . | ·03 | 25·14 | 3·08 | 28·21 | 1·68 | 18·28 | 1·89 | 11·59 |
| FeO . . | 9·88 | 1·60 | 11·20 | 3·28 | 8·57 | 3·84 | 4·51 | — |
| CaO . . | 11·79 | ·01 | 9·58 | ·02 | 9·11 | ·10 | 11·79 | ·01 |
| MgO . . | 9·54 | ·09 | 5·63 | ·08 | 7·74 | ·27 | 10·95 | ·20 |
| MnO . . | ·48 | ·06 | — | — | ·41 | — | ·34 | — |
| $Na_3O$ . . | 1·19 | — | 2·09 | ·06 | 2·38 | ·54 | ·97 | ·13 |
| $K_2O$ . . | ·11 | ·16 | ·60 | ·07 | 1·55 | ·24 | ·06 | ·10 |
| $H_2O$ . . | ·35 | 20·52 | ·30 | 19·93 | ·35 | 19·90 | ·43 | 27·84 |
| $P_2O$ . . | ·06 | ·002 | ·008 | ·001 | ·01 | ·01 | Trace. | Trace. |

(*For description of columns see opposite page.*)

| | | |
|---|---|---|
| 1. | *a.* Hornblende Schist<br>*b.* Aluminous laterite | Yarikita, Amacura River. |
| 2. | *a.* Diabase<br>*b.* Aluminous laterite | Tumatumari, Potaro River. |
| 3. | *a.* Diabase<br>*b.* Aluminous laterite | Kumaru, Demerara River. |
| 4. | *a.* Epidiorite<br>*b.* Aluminous laterite | Issorora, Aruka River. |

In addition, Harrison gives analyses of low-level laterite from the same localities :—

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ free | 19·05 | 12·28 | 4·75 | 2·52 |
| $SiO_2$ | 21·71 | 21·89 | 25·57 | 18·03 |
| $TiO_2$ | 2·59 | ·38 | 4·43 | 2·03 |
| $Al_2O_3$ | 23·26 | 24·94 | 21·30 | 27·41 |
| $Fe_2O_3$ | 18·03 | 26·93 | 28·72 | 35·75 |
| FeO | 1·34 | 1·36 | ·05 | ·16 |
| CaO | ·01 | — | — | ·12 |
| MgO | ·03 | ·68 | ·11 | ·55 |
| MnO | ·60 | — | — | ·02 |
| $Na_2O$ | ·03 | ·02 | ·03 | ·07 |
| $K_2O$ | ·09 | ·05 | ·05 | ·21 |
| $H_2O$ | 13·75 | 11·29 | 13·79 | 13·31 |
| $P_2O_5$ | ·014 | ·16 | ·001 | — |

1. Low-level laterite, Yarikita.
2. ,, ,, Tumatumari.
3. ,, ,, Kumaru.
4. ,, ,, Issorora.

According to Sir John Harrison, the bauxites of British Guiana are true aluminous laterites, having been formed under sub-aerial conditions, and are the residual weathering products of altered dolerites (diabase) and hornblendic rocks. The presence of the bauxite under heavy covers of alluvium and exposures in stream beds and banks, etc., and the existence of a drowned-river valley to the northward of the present mouth of the Berbice River, suggest that the coastal tract has been subject to considerable subsidence since the bauxite first formed. In view, however, of the apparent rejuvenation of some of the rivers, it is possible that an uplift was now in progress.

It is impossible, in the absence of fossiliferous rocks, to fix the maximum geological age of the formation of the laterites of British Guiana, but the available evidence points to it as being since the Eocene period.

The production of bauxite since the beginning of operations is given by L. T. Emory as ;—

| Year. | Long Tons. | Year. | Long Tons. |
|---|---|---|---|
| 1917 . . | 2,037 | 1922 . . | None. |
| 1918 . . | 4,199 | 1923 . . | 100,346 |
| 1919 . . | 1,967 | 1924 . . | 154,324 |
| 1920 . . | 22,084 | 1925 . . | — |
| 1921 . . | 19,694 | 1926 . . | — |

## SURINAM OR DUTCH GUIANA.

The laterite and bauxite found in this colony constitute an eastward continuation of the occurrences of British Guiana, only here the laterite areas are closer to the coast. Van Bemmelen (1904) and G. C. Dubois (1903) have discussed the Surinam laterites, and published the results of their investigations, with analyses, in two valuable papers. The origin of the laterite is similar to that of British Guiana, *i.e.* it is the sub-aerial weathering product of certain, rather peculiar, pre-cambrian diabases (epidiorites), and overlies the altered diabase in the majority of cases. More recently (1921) E. A. Douglas and F. O. Dentz have respectively described (in Dutch) the utilisation and organisation of the work connected with the development of the Surinam bauxites. Among the localities specially mentioned are the Nickerie district, and in the valley of the Surinam River at the following localities: Onoribo, on the Para Creek; Rena Reu, Porto Rico; on the Cotteca River; and on the Marechals branch of the Surinam River. Parimaribo lies at the mouth of the Surinam River, while New Rotterdam lies north of the junction of the Nickerie stream with the river Corentyii, which separates Surinam from British Guiana. The bauxite is being worked by the Surinaamsche Bauxite Maatschappy, a sub-

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ free . | ·3 | — | — | — | 8·5 |
| $SiO_2$ . | 1·20 | 7·0 | 3·1 | 14·5 | 3·1 |
| $TiO_2$ . | ·9 | — | — | — | 3·0 |
| $Al_2O_3$ . | 64·6 | 63·3 | 52·5 | 48·5 | 30·4 |
| $Fe_2O_3$ . | 1·2 | 10·5 | 14·4 | 21·6 | 35·7 |
| CaO . | Traces. | 1·0 | 1·5 | 1·0 | ·5 |
| MgO . | Traces. | — | Traces. | — | ·2 |
| $H_2O$ . | 31·8 | 17·6 | 27·6 | 14·0 | 9·0 |

1. Onoribo, Para Creek, Surinam River.
2. Oolitic bauxite, Surinam (Dubois).
3. " " "
4. " " "
5. Laterite, Nickerie District (Van Bemmelen).

sidiary of the Aluminium Company of America, who hold concessions in the Surinam River tract, and have established a drying plant and docks at Moenge, 100 miles above Parimaribo. Their monthly exports are said to average 7000 tons of *undried* ore.

The above analyses have been taken from Bemmelen's and Dubois' papers.

These show various qualities, from a rich bauxite to a typical laterite.

## French Guiana.

Eastward from Surinam, laterite of a rich aluminous type (bauxite) has been reported to occur in the French Guiana about Boulanger Creek. In 1921 the Guiana Development Company appear to have begun exploratory work on an area in the valley of the Marowine stream, but no exports of bauxite from French Guiana have yet been recorded.

As regards the quality of bauxite from French Guiana, Ed. Jannettaz gives the following analyses :—

| | 1 | 2 | 3 |
|---|---|---|---|
| $Al_2O_3$ . . . | 64·0 | 63·3 | 12·11 |
| $Fe_2O_3$ . . | 1·50 | 7·5 | 67·84 |
| MgO . . . | 1·0 | — | — |
| $H_2O$ . . . | 33·5 | 29·2 | 19·65 |

1. Compact, pisolitic, grey to red bauxite.
2. Compact, red bauxite (sp. gr., 2·545).
3. Dark, pisolitic, ferruginous laterite.

The last is a rich iron ore similar to that found in Cuba.

## Brazil.

The following writers refer to laterite, or lateritic material, from Brazil, in the vicinity of Rio de Janeiro : Atterberg, Beek, Burmeister, Derby, Eschwege, R. Hermann, Heuser, and Kreplin. From the analyses supplied by Atterberg, the laterite belongs to the detrital or low-level type, and is much mixed with non-lateritic constituents.

The localities may be dismissed as useless from the point of view of aluminous laterite. They, however, indicate the possibility of finding high-level laterite in the hinterlands of Brazil. Plateau areas which have been long subject to sub-aerial conditions are likely to have cappings of true rock-laterite in which segregations of rich aluminous material may occur. Bauxite was reported by J. C. Branner to occur in the lateritic iron ore deposits of the district of Minas Geraes, but no particulars have been made public. More recently discoveries of aluminous laterite are said to have been made in North-Eastern Brazil in the Para River tract.

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ . . | 39·44 | 40·87 | 42·61 |
| $TiO_2$ . . | 3·68 | 3·03 | 3·64 |
| $Al_2O_3$ }<br>$Fe_2O_3$ } . . | 36·18 | 37·93 | 36·61 |
| MgO . . | ·2 | Trace. | ·12 |
| $Na_2O$ . . | ·60 | ·79 | ·40 |
| $K_2O$ . . | ·50 | ·88 | ·30 |
| $H_2O$ . . | 15·0 | 13·60 | 14·30 |
| Miscellaneous . | 4·40 | 2·90 | 2·02 |

1. Santa Teresa (Atterberg).
2. Corcovada.
3. Itaiaya.

## ASIA.

### THE BAUXITE OCCURRENCES OF INDIA.

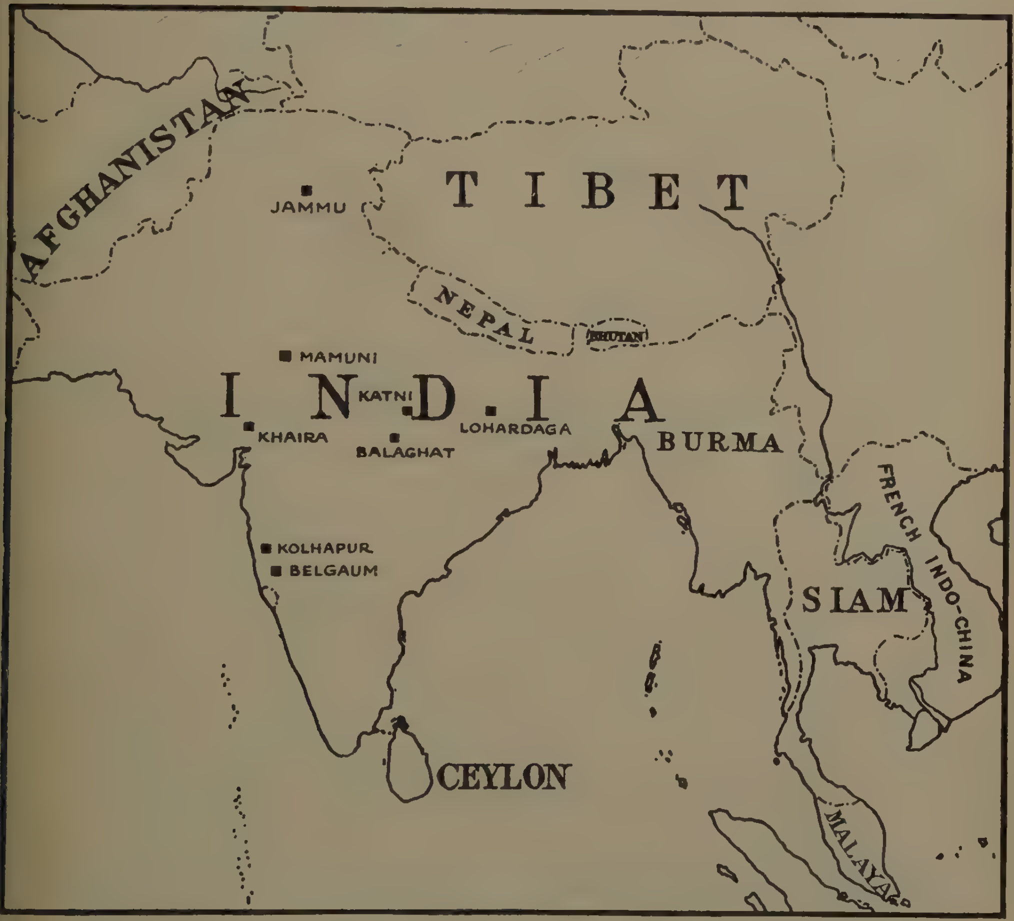
The enrichments of aluminium ore occur in widely separated areas, some in British territory, others in the Indian States. Some new localities are mentioned, but these were found during the examination of previously known occurrences. It was impossible in the time available to search all the laterite areas of India for bauxitic segregations, nor has it been possible to visit the occurrences in Kashmir (Jammu), Rajputana (Kotah, Bikanir, etc.), Central India, Gwalior, Bhopal, the north Rewa area, the Kalahandi tracts of Orissa, and the adjacent hill region of Vizagapatam in the Madras Presidency. Laterite occurs also in Hyderabad, and possibly contains rich aluminous varieties, but the specimens which have been seen cannot be classed as bauxite.

### Bombay Presidency.

**Belgaum.**—This is a British district of the Bombay Presidency, in which are included a number of small jahagirs and talukas belonging to Indian chiefs or zamindars.

The hill nearest to Belgaum has been re-named Nauga, after the village which lies to the south of the peak, 3294 feet (15° 48′ : 74° 28′). From the plain below, almost to the top of the hill, bedded basaltic lava flows are exposed on the slopes. On the western side large quantities of bauxite boulders occur far down the slope. The ridge is capped with a narrow laterite plateau almost throughout its length. The northern half has been denuded into isolated, laterite-capped hillocks. The whole of the laterite area contains bauxite. Ore of excellent quality occurs in the northern part of the main southern plateau, which culminates in the peak 3294 feet. Practically the whole of the property, which is barely five miles to the

MAP IV.



south-west of Belgaum, lies in the Kurundvadi State. The thickness of the bauxite varies from 5 to over 25 feet in the main tableland, and the average quality varies between the two following analyses—A, southern part; and B, extreme northern hillock. It is estimated that roughly 75,000 tons of the better quality occur in the area, and that upwards of 2,000,000 tons of a poorer quality are available from this tract.

| | A | B |
|---|---|---|
| $SiO_2$ . . . . | 2·11 | 3·26 |
| $TiO_2$ . . . . | 5·95 | 2·19 |
| $Al_2O_3$ . . . . | 58·81 | 49·42 |
| $Fe_2O_3$ . . . . | 9·36 | 18·93 |
| MgO . . . . | 0·2 | ·72 |
| $H_2O$ . . . . | 23·76 | 25·48 |

Analyses made in the Geological Survey Laboratory.

South of Nauga there is a double-peaked hill, the trigonometrical height of the western point of which is 3359 feet. The mass of these hills shelters the village of Kiniya (15° 46′ : 74° 28′), from the south-west. Belgaum lies ten miles away to the north-east, and the nearest railway station is Desur, at a distance of six miles to the east. The trap base, south of this Kiniya buttress, is approximately 2430 feet near the village of Sonarwadi, and the laterite capping is of the order of 50 feet. The bauxite cappings of each of the flat-topped hills may be taken as 20 feet thick, and the quantity of bauxite available in each is calculated to be roughly 100,000 tons, of a quality not much inferior to that shown in the accompanying analyses :—

| | 1 | 2 |
|---|---|---|
| $SiO_2$ . . . . | 1·89 | 2·44 |
| $TiO_2$ . . . . | 7·90 | 6·44 |
| $Al_2O_3$ . . . . | 55·86 | 52·24 |
| $Fe_2O_3$ . . . . | 7·08 | 13·00 |
| MgO . . . . | ·24 | ·03 |
| $H_2O$ . . . . | 27·10 | 25·20 |
| Loss . . . . | — | ·65 |

Analyses by R. V. Briggs.

Messrs. Tata & Sons have done a good deal of work on this hill, and contemplate working the ore. There should be no difficulty in either building a tramway or bringing in a siding from Desur railway station. The nearest water power site is that of the Gokak Falls (forty miles from Desur to Gokak Road station), about forty-eight miles away. The nearest port for export under the existing railway facilities is Marmagoa, *via* Londa, a distance of 111 miles from Desur, and 118 miles from Belgaum.

**Kolhapur State.**—Kolhapur, the most important of the group of States of the South Mahratta country, lies between latitudes 17° 10′ 45″ and 15° 50′ 20″ N., and longitudes 74° 44′ 11″ and 73° 43′ 16″ E.

Kolhapur town (16° 42′ : 74° 16′) is connected with the Poona-Londa section of the Madras and Southern Mahratta Railway at Miraj by the Kolhapur State Railway (35 miles long).

*Radhanagri or Valivda* (1880 feet).—This lies in the valley of the Bhogavati River 12 miles east of the Phonda Pass. Except for an inlier of Kaladgi sandstones and quartzites north of Valivda, the prevailing rocks of the country are flat sheets of basaltic lavas. Extensive denudation has taken place: over 1400 feet of these lavas have been removed from the Bhogavati valley.

The elongated plateau (spur, 3244 feet), north-west of Valivda, is capped with highly aluminous laterite. An average sample collected from various parts of this peneplain has the following analysis :—

| | |
|---|---|
| $SiO_2$ | 3·44 per cent. |
| $TiO_2$ | 7·00 ,, ,, |
| $Al_2O_3$ | 59·35 ,, ,, |
| $Fe_2O_3$ | 4·25 ,, ,, |
| CaO | Trace. |
| MgO | ·64 ,, ,, |
| $H_2O$ | 25·00 ,, ,, |
| Alkalies | ·32 ,, ,, |

(Analysis by R. V. Briggs.)

The whole of the plateau at this eastern end is, to a depth of about 12 feet, composed of aluminous laterite of a quality not much inferior to that shown in the analysis. There is, on the high ground in the middle, a slight thickness (10 inches or so) of a ferruginous laterite and some yellow clayey soil. Masses and boulders of bauxite occur on the southern slopes of the ridge above Padli village. Further west on the next plateau (about north of Karanja) the quality is distinctly poorer and the laterite is more ferruginous. In the extreme west, north of Olvan, about peaks 3250 feet, 3308 feet, and 3235 feet, the capping is a ferruginous laterite.

The ridge to the south of the Bhogavati River is also disappointing, but the western portion of this area must not be taken as fully examined. Another plateau in this vicinity, which may be worth investigating, lies at about the latitude of Gargotti (16° 18′ : 74° 11′), between the Dudhganga and Vedganga Rivers.

It is difficult to determine the quantity of the bauxite or aluminous laterite which occurs on the spur north-west of Radhanagri, but it is of the order of 2,000,000 tons. There is also a large, unknown quantity of richer bauxite scattered as debris on the southern slopes of the hill and in the valley below. Unfortunately the place, though close to a road, is twenty-eight miles from Kolhapur. It has, however, some local advantages. There is a large sheet of water in the new reservoir which is being built across the Bhogavati River four miles west of Valivda. Although this dam will not give a large head of water a comparatively small hydro-electric scheme would be possible. In the vicinity of Dajipur a more suitable project presents itself. At this place, near the Phonda ghat, it would be possible to dam the river a mile south of Dajipur and obtain a catchment of 8 square miles, having a rainfall of nearly 300 inches. A great pressure would be obtained if the generating plant were erected at the foot of the ghats, 1500 feet below. This would probably involve taking the ore further away from Kolhapur and nearer to the Ratnagiri coast. Devgad, thirty-three miles away on the coast due west of Phonda, is the nearest port. Kharepatan, on the Wagotna River, is at a distance of twenty-four miles, but the river is only navigable at flood tide by shallow draught launches.

*Dhangarvadi* (16° 55′ : 73° 53′ ; 3335 feet).—This overlooks the main road from Kolhapur *via* the Amba Pass to Ratnagiri in the upper valley of the Karvi nala. Malkapur lies five miles due east. (See 1 sheet No. 205, Bombay.) There is an extensive plateau to the south and west of the village, partly included in the Vishalgad jahagir. A road from Malkapur passes to the south of the hill mass of Dhangarvadi to Anaskura, so that, if any bauxite is discovered in the laterite capping of this plateau, it could be transported round the western side of the tableland, at the head of the Shali stream, and southward by spur 3142 feet to Padarpani, where the present road crosses. My colleague, Mr. H. C. Jones, visited this area after I had drawn attention to it, and has found an attractive occurrence of good bauxite. The quantity is thought to exceed that of Radhanagri. Kolhapur is the nearest railway station, but in view of the hydro-electric facilities at Anaskura, the Rajapur route to the sea might have decided advantages.

*Patagaon* (16° 8′ : 73° 59′).—North of this village there are plateaux of over 3250 feet. Two miles upstream from the village, on the Vedganga River, there is a possible dam site, while south of hill 2326 feet (see 1 sheet No. 208, Bombay), at Hanumanta, 2023 feet, there is an ideal place for an outfall having a head of 1500 feet. A power station could be built at the deserted site of the village of Vashi, 523 feet. An old road runs out westward along the Karli valley to Savantwadi and Vengurla. The rainfall on the Patagaon catchment is over 200 inches, while the drainage area is quite 8 square miles, and could be increased.

**Thana District.**—My colleague, K. A. K. Hallowes, tells me that during his investigations of the geology of Salsette, near Bombay, he located small cappings of laterite on Baumdongri (19° 10′ : 72° 57′) and Bombassadongri, 1280 feet (19° 11′ : 72° 57′), hills on the ridge to the west of the valley between the Tulsi and Vehar lakes, and that he noted a larger capping on Kaneri peak, 1538 feet

(19° 13′ : 72° 58′) above the well-known caves of the same name. The region consists of trap rocks, ash beds, and basaltic lava flows of Deccan trap age. From the analyses he has obtained through the Director of Commercial Intelligence, Bombay, it is evident that bauxite of good quality occurs in the two localities first named, but as no prospecting work has yet been carried out, it is difficult to estimate the quantities of bauxite available.

In view of the above interesting discovery attention may also be directed to the possibility of finding aluminous laterite further to the north, beyond Bassein creek, on Kamandrug hill, 2151 feet (19° 23′ : 73° 1′), and the tableland of Tungai, 2056 feet (19° 27′ : 72° 58′).

**Khaira District.**—By far the greater portion of the annual Indian output of bauxite is obtained from mines located at Kapadvanj. This place is on a railway 28 miles north-east of Nadiad on the B.B. and C.I. Railway, between Baroda and Ahmedabad. The operations are conducted by the Shivrajpur Syndicate, Ltd. The ore is used almost entirely by petroleum companies for the purification of kerosene. It occurs as an aluminous laterite in loose boulders having a decided pisolitic texture. The ore lies on the surface and has merely to be dug out. Average analyses of (1) high-grade and (2) low-grade ore are as below :—

| | 1 | 2 |
|---|---|---|
| $SiO_2$ | 1·20 | 1·53 |
| $T_1O_2$ | 6·71 | 7·14 |
| $Al_2O_2$ | 55·41 | 53·10 |
| $Fe_2O_3$ | 7·00 | 9·43 |
| Loss on ignition | 29·68 | 28·80 |

## HIMALAYAN REGION.

**Jammu (Kashmir).**—Jammu is the most southerly of the Kashmir divisions. It lies south of the Pir Panjal range, and is drained by the Chenab River. The climate is that of the sub-montane tracts of the Punjab Himalaya. It is hot in May and June, and subject to monsoon conditions ; the rainfall totals over 37 inches yearly. The coalfield of Sangar Marg (33° 11′ : 74° 38′) is almost exactly twelve miles due west of the sharp south bend of the Chenab River near Arnas.

A bed of bauxite, evidently interbanded in the section, is exposed near the village of Chakar. The outcrop varies from 7 to 10 feet in thickness, overlies a siliceous breccia, and with it separates the underlying (Jurassic ?) "great limestone" from the overlying Sabathu coal beds. The amount of bauxite, assuming 4 feet worth working, exposed at the surface in practically horizontal beds near Chakar, is estimated at over a million tons. This quantity requires simple quarrying. In addition, there is the bed under the Sabathu coal strata. This would have to be mined; the quantity, though not known, is probably much larger than that of the exposed rock.

The following analyses, given by C. S. Middlemiss in a preliminary report, though proving an aluminium ore with a high alumina content, at the same time reveals a considerable percentage of silica. If this proportion of silica does not affect the value of the ore for the extraction of aluminium, then there is abundant reason for the development of the deposit.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $Al_2O_3$ . . | 60·65 | 69·90 | 62·75 | 67·20 | 50·05 | 39·20 | 62·85 |
| $TiO_2$ . . | 4·05 | 3·38 | 3·00 | 2·45 | 2·40 | 2·00 | 3·45 |
| $Fe_2O_3$ . . | 0·90 | 1·08 | 0·85 | 0·80 | 0·50 | 0·65 | 0·55 |
| $SiO_2$ . . | 21·40 | 12·85 | 19·25 | 14·40 | 35·80 | 48·70 | 23·30 |
| $H_2O$ (combined) | 11·00 | 10·90 | 12·80 | 13·15 | 10·05 | 8·35 | 8·75 |

A railway for the opening up of the coalfield of Sangar Marg has long been considered, and this might possibly be worth attention, in view of the value of the bauxite.

Sir H. H. Hayden has discussed the use of the coal, and also of a power site on the Chenab River in connection with the bauxite (in an unpublished report), and it is now necessary for the Kashmir Durbar to either work the bauxite themselves or to lease the property to a reliable firm.

There is a railway terminus at Jammu, the winter capital of Kashmir, and it would be quite a simple matter, presuming always that the bauxite is of a suitable quality, to export the reduced aluminium to the markets of India. Aknur has been considered in connection with a hydro-electric scheme. This place is connected with Jammu by canal, and from the latter place by a navigable river with Wazirabad on the main North-Western Railway.

## The Central Provinces.

**Jabalpur (Jubbulpore) District.**—Most of the laterite areas are conveniently situated to the railway between Jabalpur and Katni (Katni-Murwara) (23° 50′ : 80° 28′), at which latter place aluminous laterite was known to occur as early as 1883. Within recent years, through the energy of Sir Thomas Holland and Mr. P. C. Dutt, these Jabalpur deposits have been proved to be of very good quality. The best known areas lie within a radius of fourteen miles to the south of Katni, and never more than three miles from the railway. The main motor road from Katni to Jabalpur also passes through the area.

In alphabetical order, the aluminous laterite areas are as follows:

Amochh (1); Bargawan Hill, Katni (2); Bijeraghogarh (3); Chhapra (4); Dhangawan (5); Flag Staff Hill, Katni (6); Gosalpur (7); Hatbai Hill (8); Khajuri (9); Kusmi (10); Mahgawan (11); Murwara Hill, south (12); Padarwara (13); Ponri Hill (14); Saraswahi (15); Sheorajpur, Bhanpura (16); Tharka (17); Tikaria (18); Tikaria, east of Kusmi (19); and Tikuri (20). They are grouped round the railway stations of Katni, Niwar, Sleemanabad, Dundi, and Gosalpur. It is proposed to discuss the various deposits in the order that they could most conveniently be visited on a traverse northward from Jabalpur.

*Bargawan Hill* (23° 49′ : 80° 23′).—The bauxite deposits of this concession lie in the south-east corner of the property, and extend up to and under the main road to Jabalpur. In the southern part there is an appreciable covering of ferruginous laterite, but the property is good and, though not quite so well placed as that of the lime works or the Cement Company, the disadvantage is very little if large outputs become possible. The section of bauxite exposed in the borrow pit by the road side shows roughly 8 feet, and the prospecting pits have proved an average thickness of a little more. It is an approximate statement, but the quantity of bauxite in this property is roughly 1,200,000 tons of fair quality ore, half of which may be of a composition approaching that of the following analyses. The total bauxite available for all purposes for which the substance may be used is large, of the order of 4,000,000 tons, but this includes much highly ferruginous laterite.

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ . . | 1·18 | 1·40 | 1·10 | 4·38 |
| $TiO_2$ . . | 8·80 | 8·75 | 8·75 | 7·62 |
| $Al_2O_3$ . . | 60·23 | 60·35 | 61·30 | 60·10 |
| $Fe_2O_3$ . . | 2·64 | 2·50 | 2·50 | 3·08 |
| CaO . . | ·82 | ·67 | ·46 | ·67 |
| MgO . . | ·30 | ·31 | ·33 | ·27 |
| $H_2O$ . . | 25·40 | 25·50 | 25·55 | 23·68 |
| Loss . . | ·63 | ·52 | ·01 | ·20 |

(Analyses by R. V. Briggs, on behalf of Messrs. Holmes, Wilson & Co.)

1. Sample taken at north end of laterite area.
2. From prospecting pit at south end of laterite area.
3. Average from centre of area.
4. Bulk sample.

*Tikaria* (23° 49′ : 80° 23′ 30″).—Laterite covers the highest parts of the hills in this tract. The thickness of the laterite varies from 4 feet in the north to more than 15 feet in the south. The substance is pisolitic, varying from a surface ferruginous laterite to a pink or grey bauxite below. The northern part of the deposit lies in the property belonging to Messrs. H. F. Cook & Sons, while the southern portion is situated in the Cement Company's concession. The composition varies from a rich, pisolitic, iron ore, sometimes almost entirely dehydrated into hematite, though there are all stages, to a rich hydrous limonite. Similarly, the laterite, which is bauxitic, shows evidence of dehydration, though in this type of the rock the phase or degree of dehydration is not as advanced as in the ferruginous variety. There are all stages in the composition of the laterite, from the dark red hematitic, and the bright reddish-yellow limonitic substance to the pink or cream grey rock. The total quantity of laterite is large, and about half of the total is rich bauxite of an average composition not much inferior to that shown in the following analyses :—

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $SiO_2$ . . | 2·76 | 2·28 | 2·0 | 1·52 | 1·40 | 0·38 |
| $TiO_2$ . . | 7·80 | 7·64 | 8·43 | 9·70 | 3·20 | 11·61 |
| $Al_2O_3$ . . | 57·58 | 59·77 | 57·01 | 60·70 | 65·10 | 65·48 |
| $Fe_2O_3$ . . | 2·10 | 4·35 | 4·66 | 2·64 | 1·84 | 3·77 |
| CaO . . | ·72 | — | — | — | ·45 | — |
| MgO . . | — | — | — | — | — | Trace. |
| $H_2O$ . . | 28·48 | 25·78 | 27·50 | 25·98 | 28·10 | 18·32 |
| Moisture . . | — | — | — | — | — | 1·06 |

1 to 4. Analyses by A. Macdonald for Industrial and Cement Co.
5. Analysis by Searle, London, for Industrial and Cement Co.
6. Analysis by T. R. Blyth, Geological Survey Laboratory (specimen J.709).

The above analyses are of the rich grey bauxite, except No. 3, which is of the pink variety.

The following analyses were made on behalf of the Katni Cement and Industrial Company by A. Maret and Ch. Delattre of Paris. The samples were again all picked specimens of the grey bauxite :—

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . | 1·20 | 1·58 | ·78 | 1·72 | 2·00 | ·68 | 1·56 | ·44 | ·76 | ·72 |
| $TiO_2$ . | 7·01 | 8·22 | 8·60 | 10·73 | 8·60 | 6·85 | 8·45 | 10·73 | 7·83 | 10·885 |
| $Al_2O_3$ . | 60·49 | 59·78 | 55·11 | 56·87 | 57·15 | 56·36 | 57·65 | 65·29 | 58·61 | 62·05 |
| $Fe_2O_3$ . | 2·50 | 2·20 | 7·80 | 2·90 | 2·75 | 7·80 | 3·30 | 3·98 | 3·56 | 5·87 |
| Loss . | ·27 | ·12 | ·28 | — | ·37 | ·12 | ·08 | ·20 | ·28 | ·05 |
| $H_2O$ . | 28·53 | 28·10 | 27·46 | 27·86 | 29·13 | 28·20 | 28·96 | 19·36 | 28·96 | 20·43 |

The approximate quantity of bauxite in the Tikaria section (as defined in this report it contains part of the land of the village of Tikuri) is of the order of 7 million tons, but of this it is doubtful if there are more than 2 million tons of a quality equal to that of the above analyses. The quantity is equally divided between the two firms who hold the area. There is therefore about one million tons of good quality bauxite in the lime works property, and approximately the same quantity in the Cement Company's concession. The road that leads west to the main Jabalpur road from the factory of the Cement Company separates off the Bargawan and Tikaria bauxite deposits from that of Flag Staff Hill to the south.

*Katni*—A mile south of the Katni railway station, and just north of the bridge-crossing, pink bauxite is exposed in the railway cutting. This is the northern end of a long strip of bauxite which lies east of the Tikaria deposit of Murwara Hill. The cart road from Tikaria village to the cement factory south of Tikuri follows this hummock of aluminous laterite. Halfway between Tikaria and Tikuri there is an isolated hillock of pink, pisolitic bauxite. This hill marks the south margin of the Katni deposit. The main portion of this deposit lies under 3 or 4 feet of black soil in the lowest ground to the east of the cart road. The deposit exposed in an excavation in the field is about 8 feet thick, and composed of loose nodules of pisolitic, grey bauxite. The structure of the nodules is concentric, and they vary in size from the size of peas to that of potatoes. Between the isolated hill in the south and the valley deposit there are occasional patches of pink, pisolitic bauxite. The actual concontinuity of the deposit has not been properly tested, but the quality is excellent, and the quantity, including the hill in the south, probably exceeds 1,500,000 tons, nearly all of which is good bauxite; of this there are possibly 300,000 tons in the northern part in the vicinity of the village immediately south-west of the bridged railway-crossing.

*Tikuri Deposit.*—Between the laterite areas of Tikaria and Katni already described there is a low valley in which the underlying limestones are exposed and have been quarried. In the south, at the head of this valley, there is a little saddle over which the path leads to the cement factory. East of the path and south of the isolated bauxite hillock there is the village of Tikuri, situated on another bauxite hillock. A well to the south-west of the village shows 18 feet of grey and pink pisolitic bauxite overlying the mottled, laminated lithomarge. These clays are exposed in all the pits at the saddle. The laminations have a general north-west dip, but the dip is as variable as the colour of the lamination. A large part of the laterite of this area is rich bauxite, but unfortunately located under and around the village of Tikuri, so that, if the deposit is to be worked, some terms would have to be made for building a new village in the neighbourhood. This should not prove difficult or expensive.

The quantity of bauxite in this section is approximately the same as that in the similar section in the north near the railway-crossing, *i.e.* 300,000 tons. The quality is similar, and, though variable, it approximates on the average to the following composition :—

| | 1 | 2 |
|---|---|---|
| $SiO_2$ . . . | 2·70 | 1·52 |
| $TiO_2$ . . . | 5·96 | 9·70 |
| $Al_2O_3$ . . | 54·76 | 60·70 |
| $Fe_2O_3$ . . | 10·08 | 1·92 |
| $H_2O$ . . . | 25·90 | 25·98 |

Analyses by A. C. Macdonald for the Katni Cement and Industrial Co. No. 1 is pink-red bauxite, No. 2 is grey bauxite.

*Flag Staff Hill* (23° 48′ : 80° 23′).—This area lies south of the road from the main Jabalpur road to the Katni Cement and Industrial Company's factory. It is part of the wooded, laterite-capped mass of hills which extend southward from Murwara Hill (1376 feet). The deposit resembles those of Bargawan and Tikaria. It is not so thick as might be anticipated, owing to the irregular ridge in the older rocks below. The ground near Tikuri, where the other bauxite occurs, is at a much lower level. The surface rock is ferruginous laterite, but this passes down into rich aluminous laterite. The tract has not been fully prospected, but the pits which were put down proved over 10 feet of good quality bauxite.

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ . . | 16·59 | 8·11 | 3·30 | 2·70 |
| $TiO_2$ . . | 3·24 | 7·39 | 7·88 | 5·96 |
| $Al_2O_3$ . . | 38·06 | 48·07 | 59·16 | 54·76 |
| $Fe_2O_3$ . . | 20·24 | 11·00 | 12·64 | 10·08 |
| $H_2O$ . . | 22·86 | 24·42 | 17·16 | 25·90 |

(Analyses by A. C. Macdonald for the Katni Cement and Industrial Co.)

1. Ferruginous, lateritic gravel on hill side.
2. Red, aluminous laterite from small hill.
3. Ferruginous, lateritic boulders on the hill.
4. Red, aluminous laterite from top of hill.

Analysis 4 is a fair average of the quality of the ore to be expected if the deposit is opened up. The quantity is similar to that of Bargawan. There is roughly 1 million tons of good bauxite and 3 million tons of poorer ore.

**Balaghat District.**—Bauxite was first discovered in this district of the Central Provinces by Dr. L. L. Fermor, who located deposits at Rupjar, Gudma, Ukna, Samnapur, and Tipagarh Hill ; and a visit by Sir H. H. Hayden, later in the same year, led to the discovery of further deposits in the same area, and subsequent work of private prospectors led to the discovery of many other deposits. The bauxite is excellent in quality in several places, but the long distance over difficult country has for the present retarded development.

### BIHAR AND ORISSA.

**Palamau District.**—In the extreme southern part of the district lies the Chhechhari valley, in which is situated the large village of Mhowadand (23° 24′ : 84° 10′). To the west are the laterite scarps of the Jamira Pat on which is the Palamau village of Orsa.

*Netarhat.*—This lies to the east of the Chhechhari valley, and is a magnificent laterite-capped plateau of moderate size, 5 miles by 3. At the southern end of the plateau bauxite of good quality has been collected by Sir H. H. Hayden, but the quantities available, though not small, occur in the neighbourhood of the station and the Government House chalet, and are not enough to warrant the suspension of building houses with a view to quarrying bauxite.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ . . | ·99 | 1·79 | 2·18 | 1·01 | ·08 |
| $TiO_2$ . . | 12·00 | 3·30 | — | 8·12 | 6·04 |
| $Al_2O_3$ . . | 60·66 | 64·64 | 64·41 | 59·32 | 60·76 |
| $Fe_2O_3$ . . | 4·52 | 6·21 | 9·50 | 6·34 | 4·52 |
| CaO . . | — | ·04 | ·23 | — | — |
| MgO . . | — | ·02 | ·12 | 1·21 | — |
| $H_2O$ . . | 22·24 | 24·00 | 23·56 | 25·91 | 29·45 |

1. No. 1118 Rock Register collected by H. H. Hayden, Geological SurveyLaboratory.
2. Analysis by Dr. Warth.
3. Specimen collected by H. H. Hayden, Geological Survey Laboratory.
4. ,, ,, ,, ,, ,, ,,
5. ,, ,, ,, ,, ,, ,,

The above specimens are of compact, greasy, grey bauxite, and are associated with more ferruginous types. The north-east corner of Netarhat is distinctly poor in aluminous laterite, and Daswan Pat contains highly ferruginous laterite. Bauxite occurs on the western scarp and in the north-west corner.

**Ranchi District.**—In the western tracts of the Ranchi district, west of Lohardaga, 2205 feet (23° 26′ : 84° 43′), there is a series of flat-topped laterite-capped plateaux which extend to the boundaries of Sirguja and Jashpur. They are evidently the eastern remnants of a great tableland, which was continuous from Mandla and Amarkantak across the upper reaches of the Son valley to the Main Pat, the Khuria highlands and the Jamira Pat. The essential point about this ancient tableland was its trappean character.

*Dudmatia Pat*, 3476 feet (23° 29′ : 84° 38′).—To the south-west Daldalia Pat faces Lohardaga from the west-north-west at a distance of barely six miles. This is the first and nearest of the higher, laterite-capped hills which are seen when looking west from Lohardaga. It gets its name from the occurrence of white kaolin, which is exposed on its southern slopes under the laterite. Grey pisolitic bauxite, with a thickness of 22 feet, is seen in the scarp section to the south-east of the point marked on the map as Baghru Hill, 3476 feet. Owing to the high percentage of titania, the quality may not be as good as the appearance of the specimens would indicate. However, the $TiO_2$ may not be uniformly distributed in the bauxite in such large percentages as shown :—

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ . . | ·36 | ·16 | 2·32 | 4·28 |
| $TiO_2$ . . | 17·24 | 13·81 | 10·26 | 9·52 |
| $Al_2O_3$ . . | 49·72 | 52·45 | 59·99 | 57·23 |
| $Fe_2O_3$ . . | 8·68 | 8·68 | 3·94 | 3·94 |
| MgO . . | 2·22 | 1·28 | 0·25 | ·34 |
| $H_2O$ . . | 22·20 | 23·94 | 23·40 | 23·00 |

Specimens from Dudmatia Pat, Geological Survey Laboratory.

This bauxite becomes furruginous both northward and southward along the scarp, and the quality is poor, both at the north and south extremities of the plateau. Good bauxite is seen on the ridge to Daldalia Pat, and on the south-west corner of that plateau. Calculating only on marginal enrichments, it is estimated that 500,000 tons of bauxite of a quality similar to that shown in the above analyses should be obtainable from Dudmatia Pat.

*Dudha Pat and Paharikona Pat.*—To the south of Sendur village (23° 26′ : 84° 33′) there is a strong ridge of dark grey granulite (3280 feet) which connects Paharikona Pat on the west with Dudha Pat on the east. Paharikona Pat is capped with laterite in which, in places, aluminous varieties occur, but the plateau requires further examination. No prospecting pits have been put down, and it is difficult to say if the bauxite that is known to occur is worth exploitation.

Dudha Pat, on the other hand, contains a large quantity of excellent bauxite. Analysis :—

| | |
|---|---|
| $SiO_2$ . . . | 1·54 per cent. |
| $TiO_2$ . . . | 8·70 „ „ |
| $Al_2O_3$ . . . | 62·00 „ „ |
| $Fe_2O_3$ . . . | 5·99 „ „ |
| $H_2O$ . . . | 21·96 „ „ |

The plateau has been considerably denuded, and the top is not flat. The south side of the hill has practically no real scarp. The laterite, though aluminous, is not rich. The top of the hill along the eastern margin shows frequent exposures of grey, pisolitic bauxite, sometimes as compact rock, but more often as a loose, pellet gravel. One little hillock contains nearly 25 feet of ore. In the north-west corner the bauxite is seen in a scarp some 20 feet down the slope from the top of the hill, evidently at a lower level than the little hillock already mentioned. The quality is very good in appearance, and a thickness of over 10 feet is seen. The village of Sendur lies immediately below on the track which leads east to Gamaria, and down the steep ghat to Garh Kasmar in the Lohardaga plain. The total distance from Dudha Pat to Lohardaga is about ten miles along an existing track suitable only for pack transport or very strong light carts. The quantity is difficult to calculate owing to the covering of lateritic soil at the north-east corner, but there should easily be more than 250,000 tons of bauxite of the quality shown in the above analysis.

**Kalahandi State** (*also known as Karond*).—This lies across the northern end of the Eastern Ghats and is the southern extremity of the Province of Bihar and Orissa. Peopled by Khonds, it is the tract from which certain graphite-garnet-sillimanite-quartz schists were named khondalites by T. L. Walker. The proposed and recently surveyed railway from Raipur to Vizagapatam would come southward on the eastern margin of Kalahandi into the valley of the Nagavalli river, and connect at Parvatipuram with the branch line from Vizianagram. V. Ball, speaking of this country and its laterite, says: "In the south-eastern parts of Kalahandi there are a number of *pats* from 3000 to 4000 feet high: of these I was only able to ascend one, Baplaimalai, 7 miles east of Moulpatna. Its elevation above the sea, according to the Atlas sheet, is 3587 feet, of which the upper 300 feet is formed of a bed of laterite resting on the up-turned edges of metamorphics." T. L. Walker makes no mention of any trap associated with the laterite cappings. It is quite certain from the specimens brought in by C. S. Middlemiss that the khondalite is lateritised, but the country must be considered as insufficiently examined.

The places of importance are (1) Barka station, 3414 feet (19° 43′ : 83° 12′), a boomerang-shaped, laterite-capped plateau 2 miles north of Korla Pat village; (2) Korla Pat Hill, 3981 feet (19° 34′ : 83° 14′), a long, flat-topped ridge capped with laterite, which extends for 7 miles south of the village of the same name; (3) 4 miles to the west of the village there is another long narrow ridge with laterite, between Kutligor in the north to Katgura in the south, a distance of 8 miles. The whole area, from Barka Hill southward, consists largely of charnockite gneiss with bands of khondalite. Analyses of the bauxite of Korla Pat Hill, of typical khondalite, and of the gneissose charnockite, are as below:—

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 1·37 | ·93 | ·53 | 3·75 | 16·23 | 74·17 | 75·54 |
| $TiO_2$ | — | 1·04 | — | ·37 | ·93 | — | — |
| $Al_2O_3$ | 67·64 | 67·88 | 55·35 | 47·36 | 26·82 | 17·16 | 13·75 |
| $Fe_2O_3$ | 4·27 | 4·09 | 17·00 | 23·37 | 41·69 | 7·82 | 4·99 |
| CaO | ·42 | ·36 | — | — | — | ·61 | ·94 |
| MgO | — | — | — | — | — | ·83 | ·69 |
| $K_2O$ | — | — | — | — | — | — | 3·34 |
| $Na_2O$ | — | — | — | — | — | ·49 | 1·55 |
| $H_2O$ | 26·30 | 26·47 | 27·03 | 24·47 | 14·20 | ·11 | ·28 |

1. Bauxite, Korla Pat Hill, analysis by Geological Survey Laboratory.
2. ,, ,, ,, by H. Warth.
3, 4, and 5 from the same area, analysis by P. Brühl.
6. Typical khondalite, analysis by T. L. Walker.
7. Typical acid charnockite, analyses by T. L. Walker.

P. Brühl also determined the presence of small percentages of vanadium and chromium in his anlayses.

South of Korla Pat Hill there is the imposing mass of Sijimali, 4000 feet (19° 30′ : 83° 12′), a large, laterite-capped hill, to the west of which, at a distance of 3 miles, is the flat-topped ridge of Buna or Gunjiguda, 3224 feet. Further south lies the irregular elongated plateau of Mandibisi (19° 23′ : 83° 13′), and south again there are smaller, isolated, laterite-capped plateaux near the village of Maribata (19° 15′ : 83° 12′). Baplamalai, 3587 feet (19° 21′ : 83° 2′), has already been referred to in connection with the village of Moulpatna, which lies 7 miles to the west-north-west.

The analyses of bauxite from Korlapat are so good that, if large quantities exist, the tract must prove important when the railway is constructed, as the country is not very difficult eastwards towards the Nagavali valley. This importance is heightened by the existence of possible hydro-electric sites in the adjacent Madras (Jaipur State) area to the south-west, and to the fact that a harbour is to be built at Vizagapatam.

**Madras Presidency.**—*Ganjam.*—This is most northerly of the districts of the Madras Presidency; the Eastern Ghats traverse it from north to south. The rocks exposed in the district are chiefly gneisses and schists, charnockites and khondalite. Cappings of high level, horizontal laterite are said to cover the hill-slopes between elevations of 3000 and 4000 feet. There are many peaks over 3500 feet near the coast; the points of Deodongar, 4533 feet, Singarazu, 4976 feet, and Mahendragiri, 4919 feet, all lie within easy reach of Parlakimedi (18° 47′ : 84° 7′), the terminus of the branch line from Naupada (a junction on the main line from Calcutta to Madras). V. Ball visited Mahendragiri hill and found no laterite capping on its summit, which, he states, consists of a coarse, porphyritic gneiss.

*Vizagapatam.*—This lies south of Ganjam and Kalahandi State and includes the estate of Jeypur. The country is very similar to the area to the north, and contains a large, hilly tract where the Eastern Ghats cross the district. The rocks exposed in this tract are chiefly gneisses and schists similar to those of Ganjam. Laterite is found in a similar way, though here it has been established that bauxite does occur in the laterite which caps the northern hills. It also appears that the higher peaks (exceeding 4000 feet) to the east and in the south have no laterite capping.

*North-West Corner.*—This is a southward extension of the Kalahandi country, and in it lie the following laterite-capped hills. Poragar hill, 3043 feet (19° 36′ : 82° 10′), lies 4 miles to the north-west of the village of the same name. Girliguma (19° 7′ : 82° 55′) gives its name to a plateau, 3757 feet, which lies to the south-east. There is a second plateau to the south-east of the last, locally called Gusramali, 3780 feet. A somewhat siliceous, lateritic bauxite was found on Girliguma hill. There is a long ridge of laterite-capped hills which extends southward from Lachmanigura point, 3859 feet (18° 54′ : 83° 7′), to Shoramali peak, 4380 feet (18° 52′ : 83° 6′). To the north-west and north-east of Paliura (18° 45′ : 83° 6′) village there are the peaks 4731 feet, Dumrijola, 4856 feet, and Kaliamali, 5062 feet. To the south rises the mass of Doderi, 5470 feet (18° 40′ : 83° 2′), and beyond it, through Potangi, the road from Salur crosses the ghats to Jeypur. In the extreme north-east of the district are the peaks of Kuttak, 3728 feet, Damni, 3893 feet, and Nimgiri, 4972 feet (19° 32′ : 83° 30′), which last overlooks the valley of the Nagavali stream and the last section of the proposed railway from Raipur to Parvatipuram.

The Indian occurrences of workable bauxite may be summed up as follows :—

**Jabalpur.**—The richest area is undoubtedly between Jabalpur and Katni, but this is nearly 600 miles from either Calcutta, Bombay, or the proposed harbour at Vizagapatam. The East Indian railway passes within a mile or so of all the best occurrences in this tract. There is a coalfield (Umaria) a few miles away, and Bengal coal is obtainable at a moderate price. The Katni area in the Jabalpur district is situated in the heart of India. Here bauxite averaging 56 per cent. $Al_2O_3$ should be obtainable loaded in trucks at the railway station at 4·8 rupees to 6 rupees (about 10s.) per ton. Good Bengal coal, at the same place, costs about 13 rupees per ton, and a poorer quality coal from Umaria is available at approximately 4 rupees per ton. Also, owing to the high percentage of combined water in the Katni bauxite, about 25 per cent., compared with roughly 10 per cent. in the French ore, it is likely that 2½ to 3 tons of bauxite will be necessary for the production of 1 ton of calcined alumina. The problem is therefore a mathematical one, involving railway freights. For foreign export it may be best to rail the bauxite to the Bengal coalfield, or, when the new East Indian line eastward from Katni through the Sone Valley and the Karanpura coalfields to Asansole is completed, to the Karanpura coalfield, and there purify the bauxite and export from the port of Calcutta. For purposes of reduction to aluminium in India, it may be best to establish alumina works at Katni and rail the purified material northward through Amballa to the great hydro-electric station,

ANALYSES OF INDIAN BAUXITE.

| | Jabalpur, C.P. | | | Western Chota-Nagpur, B. & O. | | | Balaghat, C.P. | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| $SiO_2$ | 1·18 | 1·40 | 2·70 | 0·08 | 2·32 | ·30 | ·58 | 1·40 |
| $TiO_2$ | 8·80 | 3·20 | 5·96 | 6·04 | 10·26 | 7·40 | 10·24 | 6·00 |
| $Al_2O_3$ | 60·23 | 65·10 | 54·76 | 60·76 | 59·99 | 66·98 | 58·83 | 58·40 |
| $Fe_2O_3$ | 2·64 | 1·84 | 10·08 | 4·52 | 3·94 | 5·92 | 2·70 | 5·00 |
| CaO | 0·82 | 0·45 | — | — | — | — | — | — |
| MgO | 0·30 | — | — | — | 0·25 | Trace. | — | — |
| $H_2O$ (comb.) | 25·40 | 28·10 | 25·90 | 29·45 | 23·40 | 21·40 | 26·80 | 28·50 |
| Alkali and moisture, etc. | 0·63 | — | — | — | — | — | 0·65 | 0·70 |

| | Kolhapur. | | Belgaum. | | Ratnagiri. | Jammu. | |
|---|---|---|---|---|---|---|---|
| | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| $SiO_2$ | 1·44 | 3·44 | 1·89 | 1·56 | 3·01 | 12·85 | 14·40 |
| $TiO_2$ | 6·32 | 7·00 | 7·90 | 3·00 | 2·16 | 3·38 | 2·45 |
| $Al_2O_3$ | 62·32 | 59·35 | 55·86 | 61·49 | 51·75 | 69·90 | 67·20 |
| $Fe_2O_3$ | 2·65 | 4·25 | 7·08 | 7·99 | 14·60 | 1·08 | 0·80 |
| CaO | Trace. | Trace. | — | 0·12 | — | — | — |
| MgO | 0·38 | 0·64 | 0·24 | 0·48 | 0·82 | — | — |
| $H_2O$ (comb.) | 26·27 | 25·00 | 27·10 | 25·15 | 27·30 | 10·90 | 13·15 |
| Losses, etc. | 0·28 | 0·32 | — | 0·21 | 0·39 | — | — |

1. Bargawan Hill (Katni), analysis by R. V. Briggs for Holmes, Wilson & Co. 2. Tikaria (Katni), analysis by A. B. Searle for Katni Industrial and Cement Co. 3. Flag Staff Hill (Katni), analysis by A. C. Macdonald for Katni Industrial and Cement Co. 4. Netarhat (Palamau), analysis Geo. Survey Lab. Calcutta, for Sir H. H. Hayden. 5. Dudmatiapat (Ranchi), analysis Geo. Survey Lab., Calcutta, for C. S. Fox. 6. Rajadera (Ranchi), analysis Geo. Survey Lab., Calcutta, for C. S. Fox. 7. Rupjar (Balaghat), analysis Imperial Institute, London. 8. Tipagarh (Balaghat), analysis Tata & Sons. 9. Panhala Fort (Kolhapur), analysis by R. V. Briggs, Calcutta, for Kolhapur State. 10. Radhanagri (Kolhapur), analysis by R. V. Briggs, Calcutta, for Kolhapur State. 11. Kiniya (south of Belgaum), analysis by R. V. Briggs for Tata & Sons. 12. Chandgad (west of Belgaum), analysis by R. V. Briggs for Tata & Sons. 13. Harnai (Ratnagiri), average of two analyses, Geol. Surv. Lab., Calcutta, for C. S. Fox. 14. Chakar (Jammu), analysis said not to be correct, by C. S. Middlemiss. 15. Chakar (Jammu), analysis said not to be correct, by C. S. Middlemiss.

which was contemplated in connection with the colossal irrigation dam (at Bahkhra) on the River Sutlej above Rupjar. It is estimated that if consumers are available this power station can develop 300,000 electrical horse-power when fully completed. It is a perfect site in every way, and power should be available as cheaply as in average European stations. The whole question with regard to the Katni bauxite, therefore, turns on the question of railway freights. The special goods freights on most Indian railways for coal varies from a maximum of about $\frac{1}{3}$ pies per maund ($\frac{3}{4}$d. per ton) to a minimum of $\frac{1}{10}$ pies per maund (about $\frac{1}{4}$d. per ton) up to distances of 300 miles, and is half this for distances greater than 500 miles.

**Ranchi.**—The bauxite area of Western Chota-Nagpur is nearest to Calcutta, but requires the westward extension of the Purulia-Ranchi-Lohardaga line of the Bengal-Nagpur railway for better facilities of transport. Bengal coal would be readily available. There is a great disadvantage in the break of gauge of railway, which will necessitate transhipment in either direction at Purulia. Western Chota-Nagpur is not so difficult of solution. Bauxite ($Al_2O_3$ from 50 to 55 per cent.) should be available at Lohardaga railway station at from 7 rupees to 14 rupees (say, 10s. to 20s.) per ton, the nearer bauxite of Dudmatiapat being very much cheaper than that of Rajadera until the railway, as contemplated, is extended westward. Although freight calculations may be slightly in favour of bringing coal to Lohardaga, there is no question of doubt that the many other facilities will be favourable to an alumina works being established at Purilia or Asansole, if the existing transhipment difficulties at Purulia can be made cheaper. The price of Bengal coal in the Jherria field is about 6 rupees per ton.

The bauxite of the Main Pat in Sirguja is nearly 100 miles from the nearest railway, so that this area is not likely to receive much attention until a railway is constructed to the State. Sirguja (Bisrampur) is a rich rice-producing country, and contains a fairly large coalfield.

There are small occurrences of bauxite on the Amarkantak plateau in Rewa State, but as this region, the source of the Nerbada River, is a place of sanctity and pilgrimage, it is certain that the priests would at first not see eye to eye with a mining company. However, the region further west along the southern margin of the uplands of Mandla appears attractive, but requires examination. The distance from a railway, however, increases with more westerly places.

**Balaghat.**—The bauxite occurrences of the Rupjar valley and the Baihar plateau (Tipagarh, etc.) in Balaghat are good, but lie more than twenty miles from the narrow gauge Gondia-Jabalpur branch line of the Bengal-Nagpur Railway. A tramway for transporting the large stocks of manganese ore near Laughor and Samnapur has long been projected. When this line is made the bauxite could be brought to the site of the proposed Uskal hydro-electric station near Bhaweli. Balaghat lies nearly halfway between Calcutta and Bombay, and the nearest coalfields are in the Pench valley in the Chindawra district, and the Wardha valley in the Chanda district. The present cost of bringing the Baihar plateau bauxite to the railway renders the area unattractive. But if the tramway is made it should be possible to get the raw material (50 to 55 per cent. $Al_2O_3$) to Gondia station on the main line of the Bengal-Nagpur railway at about 10 rupees to 12 rupees (say, £1) per ton. Coal from the Pench valley (Chindwara) and the Wardha valley (Chanda) is available at Gondia at about 8 rupees to 9 rupees per ton, and Bengal coal costs about 14 rupees per ton. An alumina factory at Gondia would be in direct touch, although over great distances, with Calcutta, Bombay, and, when the Raipur-Vizagapatam line is completed, with Vizagapatam.

The Satara district in the Bombay Presidency has so far proved disappointing, but owing to the low silica percentage some of the low-grade laterite of Panchgani, Mahableshwar, and the Yeruli tracts could be worked if transport facilities were better. There are large areas of this district further south which may contain good bauxite, but in the neighbourhood of the Koyna Valley, and the site of the proposed gigantic hydro-electric works, there is no bauxite that is suitable for present processes.

There is a small quantity of excellent bauxite at Panhala in the Kolhapur district, and a much bigger occurrence of workable bauxite near Radhanagri, north of the road leading from Kolhapur city to the Phonda Pass. There is also a possible hydro-electric site near the Pass. The nearest railway is Kolhapur, 30 miles away, and coal would have to come from the Singareni collieries of Hyderabad. However, as the railways largely use wood fuel, it is possible the same fuel, or perhaps oil, may be available for an alumina factory.

The bauxites of Belgaum are the most attractive in Western India. The occurrences are individually small and widely scattered, and without increased railway facilities most of the places would have to depend on cart and motor transport. The question of coal is nearly the same as in Kolhapur. Marmagoa *via* Londa is the nearest port for Belgaum.

**Belgaum.**—Owing to the unfavourable location of the Chandgad area the Kiniya and Nauga bauxite would alone be used for some years. This material, with $Al_2O_3$ from 50 to 55 per cent., should be available at Belgaum or at Desur station at from 5 rupees to 7 rupees (say, 10s.) per ton. Sea-borne Bengal coal would be available at Belgaum for about 27 rupees per ton, and Singarenni coal (Hyderabad) at about 14 rupees per ton. A slight calcination, not exceeding 400° C., may be considered in the question of economy for freight to Marmagoa, at which port the alumina factory would perhaps be best established for foreign export.

**Ratnagiri.**—In the north of the Ratnagiri district, close to the coast near Harnai, there is a possible area of workable bauxite. It has a characteristic vermicular structure, consisting of irregular tubes filled with cream-coloured bauxite in a red matrix of ferruginous matter. The analysis of the whole averages 52 per cent. alumina, 14 per cent. ferric oxide, 3 per cent. silica, 2·5 per cent. titanium oxide, and the remainder combined water, moisture, and traces of other impurities. This region would be the nearest occurrence of bauxite to the Koyna valley hydro-electric station at Chiplun. The bauxite of Harnai occurs practically on the coast, and a quality averaging 45 to 50 per cent. $Al_2O_3$ should be available in stacks on the coast for 2 rupees to 3 rupees (say, 5s.) per ton. Bengal coal would cost less than the sea-borne coal in Bombay (say, 20 rupees to 25 rupees per ton), and English coal may be procurable at a reasonable price (say, 40 rupees per ton). This area, if the bauxite occurs in sufficient quantity, would be attractive in many ways. Although it has no harbour, both the bauxite and coal could be taken down the coast to Jaigad, where Tata & Sons contemplate a harbour and large chemical works in connection with their enormous Koyna valley hydro-electric scheme. The Koyna valley lies inland about forty miles from Harnai, and Jaigad is about the same distance to the south.

**Vizagapatam.**—Bauxite of good quality also occurs in the north of the Madras Presidency and in Kalahandi State. This is at present an almost impossible tract, but the Bengal Nagpur Railway have surveyed, and propose to construct a railway from Raipur, in the Central Provinces, through part of this country to connect with the Madras line near Vizagapatam. The area has not been properly examined. Should the quantities be attractive there will be no difficulty, when the railway is built, in taking the bauxite to the coast at a fairly cheap price. The potentialities of Kalahandi and the adjacent area are unknown. Until this tract has been explored it is unwise to consider its possibilities, however attractive its location and power prospects appear to be.

**Kashmir.**—The Jammu bauxite has already received serious consideration from the Kashmir Durbar, owing to its proximity to a possible hydro-electric site and the availability of coal of Tertiary age. The upper 4 feet of this bauxite is said to be workable, but it passes downward into highly siliceous material somewhat similar to the bauxite of County Antrim. The area is rather inaccessible, but lies on a proposed railway alignment, which had been under consideration before the discovery of the bauxite by Mr. C. S. Middlemiss, a retired member of the Geological Survey of India. The bauxite in Jammu occurs in close proximity to outcrops of Tertiary coal, as well as to a good hydro-electric power site. If the bauxite is considered suitable for reduction, there is little doubt that an alumina factory will be established. An alumina factory alone, unless used in conjunction with a plant for the manufacture of aluminium sulphate, would find a very serious competitor in the Bengal coalfield in questions of export. Large supplies of aluminium sulphate are imported into India for various purposes, and the imports are increasing.

## CHINA.

Kyukichi Watanabe, geologist to the Imperial Geological Survey of Japan, mentions (*Jap. Jour. Geol. Geo.*, vol. iii, No. 3-4, 1924) the discovery of an aluminous shale of high alumina content as occurring in the coalfields of Po-shan, Tzu-chuan, and Chang-chiu. From the details very kindly forwarded by him, it is evident that the material is not bauxite, however valuable it may be for refractory or other purposes.

### Pacific Islands and East Indies.

Under this heading are included the whole of the peninsula and islands from the Federated Malay States and Singapore, Java and Sumatra, Banka, Bawang and Borneo, and the many smaller islands to the south-east. Little is known exactly except that laterite exists. Scriviner, E. C. J. Mohr, J. B. Logan, Th. Posewitz, and Van Bemmelen have recorded occurrences.

There does not appear to be a record of laterite sufficiently aluminous to be described as bauxite. The laterite is most probably of recent origin, and possibly still in process of formation, but it will be remarkable if no workable aluminous laterites exist. Posewitz, writing of Banka, records its occurrence in the districts of Koba and Pangkal Pinang ; also in the adjacent island, to the east, of Billiton and in the islands of the Rhio Linga group ; discussing W. Borneo the same writer mentions Sambas, Bawang, Skadan, Pandang, Mandor, Palo River, etc.

## AUSTRALIA.

**Western Australia.**—True laterites, both highly ferruginous and also the aluminous variety bauxite, has been found on the Darling plateau and the Blackwood Ranges of this region. The occurrences are in general typical of laterite, *i.e.* as massive ferruginous cappings to the plateau and hills—irrespective of the underlying rocks, provided these are capable of yielding the lateritic constituents alumina and ferric oxide. In Western Australia the rocks usually associated with the laterite mantles are granite, diorite, amphibolite, chlorite-schists, etc. The laterite is frequently pisolitic in texture, and the more aluminous varieties are said to generally overlie the more acid rocks, *e.g.* granite.

From the writings of W. G. Woolnough ("Laterite in Western Australia," *Geol. Mag.*, 6 Dec., vol. v, 1918, p. 358), E. S. Simpson (*Geol. Mag*, 5 Dec., vol. ix, 1912, p. 399), and A. Gibb Maitland ("The Bauxite Deposits (Aluminous Laterites) of Western Australia," *W. Australia Geol. Survey Mines Handbook, Mem.* 1, Chap. II, *Econ. Geol.*, 1919), it would appear that the following analyses are representative of the class of material which has so far been met with on a large scale :—

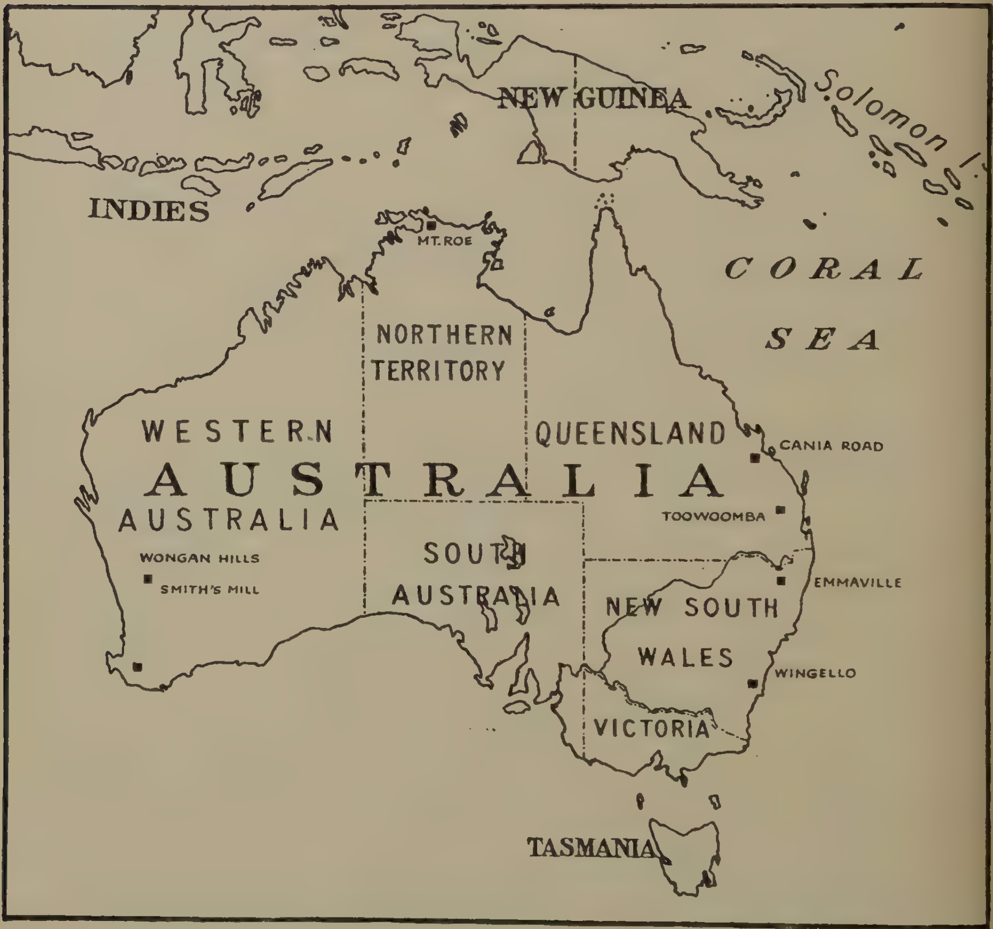
| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $SiO_2$ (free) . | 0·76 | — | — | — | — | — |
| $SiO_2$ . . | 1·77 | 13·74 | 17·17 | 5·96 | 2·67 | 2·73 |
| $TiO_2$ . . | 6·06 | 4·33 | 0·59 | 3·10 | 2·01 | 5·00 |
| $Al_2O_3$ . | 4·32 | 31·14 | 46·70 | 44·66 | 9·92 | 12·76 |
| $Fe_2O_3$ . | 80·02 | 35·54 | 10·02 | 19·08 | 78·38 | 62·67 |
| CaO . . | — | 0·16 | Trace. | Trace. | — | — |
| MgO . . | Trace. | Trace. | Trace. | Trace. | 0·35 | 0·99 |
| MnO . . | 0·13 | — | — | — | 0·07 | 0·35 |
| $P_2O_5$ . . | Trace. | Trace. | Trace. | Trace. | Trace. | Trace. |
| $V_2O_5$ . . | 0·55 | — | — | — | 0·40 | 0·15 |
| $Cr_2O_3$ . | 0·08 | — | — | — | 0·01 | 0·08 |
| $H_2O$ . . | 7·06 | 15·40 | 25·37 | 27·02 | 6·00 | 14·46 |

1. Coolgardie.
2. Mt. Baker.
3. Smith's Mill.
4. Wongon Hill.
5. Kalgoorlie.
6. ,,

*N.B.*—The Imperial Institute monograph on *Bauxite and Aluminium* (1925), page 74, gives an analysis of material from Smith's Mill as having—alumina, 50·68 per cent. ; ferric oxide, 7·14 per cent. ; silica, 16·05 per cent. ; titanium dioxide, 0·62 per cent. ; and water, 25·95 per cent.

**Northern Territory.**—In an article, "Geological Reconnaissance from Van Dieman's Gulf to the Arthur River, etc., in 1907" (*Govt. Geologists' Report, Northern Territory of Australia*, 1908, pp. 10-12), mention is made of the occurrence of a ferruginous pisolitic rock as a capping to the flat-topped summits of Mt. Roe (488 feet, R.L.) and Mt. Bidwell (426 feet, R.L.) in the Coburg Peninsula. The hills themselves consist of horizontal strata consisting of ferruginous shales, ironstone, and sandstone. The pisolitic rock consists of the following components: Alumina, 47·32 per cent.; ferric oxide, 9·74 per cent.; silica, 21·00 per cent.; and water, 22·32 per cent. The high silica content is objectionable to producers of aluminium, while ferric oxide is above the limit specified by manufacturers of alum. The material might prove suitable for the filtration of raw kerosene. This aspect if verified might prove of value should the kerosene shales of Australia be extensively distilled for an output of oil fuel. Similar pisolitic ore has proved suitable in the preparation of refractory purposes for high temperature metallurgical furnaces.

MAP V.



**Queensland.**—Laterite occurs somewhat abundantly in Queensland, and it is almost certain that bauxite will be discovered in association in quantities attractive enough for detailed examination. Certain localities have already been noted as containing aluminous laterite—possibly bauxite (see B. Dunstan, "Queensland Mineral Deposits," *Queensland Govt. Min. Jour.*, Oct. 1916, p. 475).

Among these, two are of interest from the point of view of mode of formation—the occurrence at Crow's Nest, north-north-east of Toowoomba, overlies and is genetically related to decomposed basalt; the laterite at Plainby, six miles west of Crow's Nest, appears to be the weathering product of granite which is found under the ferruginous mantle.

Other occurrences have been reported from various places, *e.g.* Cooranga, near Dykehead, in the Burnett district; Cania Road, three and a half miles south of Kroombit station, in the Port Curtis district, etc.

**New South Wales.**—Laterite sufficiently aluminous to be termed low-grade bauxite is known to occur in the Wingello district, Camden County. Other occurrences are reported from the Emmaville and Inverell districts further north. The occurrences are typical of laterite, *i.e.* red or pale pink or yellow, massive and pisolitic material, lying as a mantle over the decomposed rock of flat-topped hills and ridges. In most cases in the Wingello district the underlying rock, from which the laterite has been formed by sub-aerial weathering, is basalt. It is, therefore, presumed that the mode of formation must be similar to that which is thought to have produced the laterite and bauxite in India.

| | Murrumbah, Camden County. | Warialda Rd., 9½ Miles from Inverell. | Emmaville (Red Ore). |
|---|---|---|---|
| $SiO_2$ . . | 1·90 | 4·10 | 0·16 |
| $TiO_2$ . . | Trace. | 2·05 | 4·75 |
| $Al_2O_3$ . . | 61·46 | 41·68 | 42·20 |
| $Fe_2O_3$ . . | 1·99 | 24·18 | 28·91 |
| CaO, etc. . . | — | 0·94 | 0·82 |
| $P_2O_5$ . . | 0·08 | 0·23 | 0·26 |
| $H_2O$ . . | 30·77 | 26·34 | 23·45 |

According to Pittman ("Aluminium," *N.S.W. Dept. Mines Geol. Surv., Min. Res.*, 1901; also *New South Wales Official Year Book*, 1915, pp. 183-189), the quality of the aluminous laterite varies as follows: Alumina, 31·43 to 61·46 per cent.; ferric oxide, 1·99 to 42·21 per cent.; silica, 0·16 to 29·8 per cent.; titanium dioxide, 0·55 to 5·5 per cent.; and water, 6·85 to 32·68 per cent.

It is computed that in the Wingello district alone there is roughly a million tons of low-grade material, averaging about 35 per cent. of available alumina. This, of course, is not attractive from the point of view of an aluminium industry. The general high iron content also spoils its prospects in the chemical industry. Information regarding the quality of bauxite required in cement manufacture is not explicit enough to say whether this Wingello aluminous laterite could not be used for that purpose.

The Imperial Institute monograph on *Bauxite and Aluminium* (1925) quotes (p. 73) a few complete analyses of higher grade bauxite (see table, p. 145).

Incidentally, the above analyses show the passage from a lateritic iron ore (1), (5), and (6) through a typical laterite (2) to aluminous laterites (4) and (3), and bauxite (footnote). The presence of phosphoric acid, vanadic acid, and chromium oxide are most interesting, and there is much food for thought in a study of the water content.

Although none of the samples are exactly attractive, except perhaps that from Smith's Mill, in the south-western division, yet it would seem that a more careful search may disclose rich bauxite in re-entrant scarps or under stream beds on the laterite-capped plateaux (see "The Bauxite Resources of India," *The Mining Magazine*, vol. xxvi, No. 2, Feb., 1922, pp. 88-89).

**Victoria.**—Laterite has been observed in Victoria, but no particulars are to hand.

**Tasmania.**—The Imperial Institute monograph (*op. cit.*, p. 74) says that "bauxite is known to occur in Tasmania, but at a recent date no official examination of the deposits had been made."

## EUROPE.

### France.

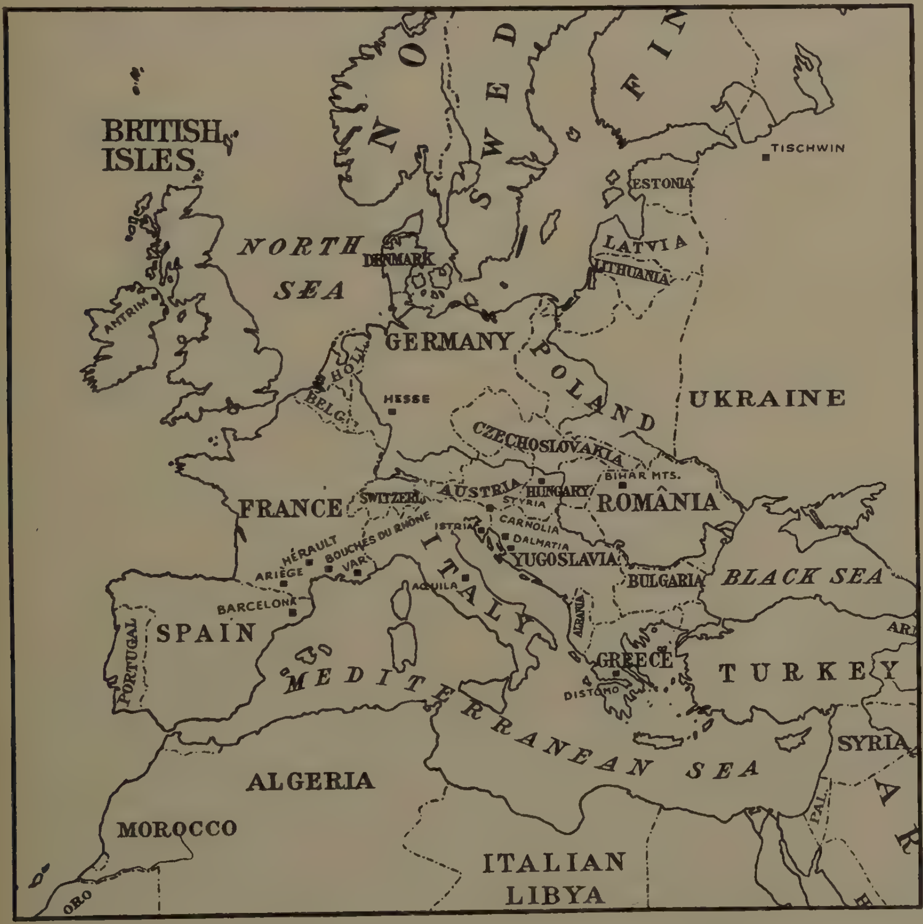
Bauxites of various degrees of richness are reported from the following Departments : Ariège, Bouches-du-Rhone, Charente, Cher, Hérault, Indre, Puy-de-Dome, Tarn, and Var.

Among the chief authorities are H. Arsandaux, M. Auge, P. Berthier, L. Collet, H. Coquand, St. Clair Deville, A. Lacroix, and F. Laur. Professor Auguste Pawlowski (see *Les Bauxites Francaises-études géologiques, statistiques et industrielles*, Paris, 1925) is also a recent worker among the bauxites of France.

To France belongs the honour of the name "Bauxite" : given by P. Berthier to the ore of Les Baux near Arles. Collet speaks as though the bauxite bed was spread out in a transgressive sheet during the Aptian and Gault interval of geological time, on an upraised surface, over rocks of several stages of the Infra-Lias and the Uriconian, and had not been covered for a long time,—the earliest sediment on it varying locally from the Cenomanian to the Danian. This would make the period of bauxite formation equivalent to the Upper Cretaceous. Suess (*Das Antlitz der Erde*) agrees with this.

He says that from Spain through the south of France, and particularly in Provence, Leymerie's Garumnian stage (of fresh-water beds) rests on the marine Cretaceous. Above the fresh-water beds, over wide areas, there is a bauxite bed, over which come fresh-water limestones. These extend from the Var across the Bouches-du-Rhone, Vaucluse, Gard, Hérault, Aude, and Ariège. In Provence the upper beds contain Physa, Lymnæa, and Planorbis. The same interruption of the marine series between the Cretaceous and the Eocene is repeated in the region north and east of the Adriatic from Carniola to Dalmatia.

MAP VI.



The climate of the south of France during the period of the bauxite formation was distinctly tropical, as judged by the fauna and flora of the upper Cretaceous in adjacent areas. The overlying beds, however, indicate a change to a more temperate climate in the early Eocene, followed later in the middle Eocene period by a return to tropical conditions.

**Ariège.**—This tract lies along the northern slopes of the Pyrenees, where St. Paul and Suzan are two localities mentioned in connection with analyses of bauxites.

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ . . . | 18·7 | 8·9 | 12·9 |
| $TiO_2$ . . | 1·9 | ·6 | 1·9 |
| $Al_2O_3$ . . | 54·2 | 58·7 | 58·8 |
| $Fe_2O_3$ . . | 7·8 | 20·8 | 12·7 |
| $H_2O$ . . | 19·7 | 10·0 | 13·2 |

1. Only 8 per cent. $H_2O$ given off at 250° C., 14·9 per cent. at 600° C., and the remainder at 960° C. 9 per cent. of the $Al_2O_3$ is soluble in HC and 3·6 per cent. of the $H_2O$ is in the soluble portion. Saint Paul, Ariège. (M. Blot, see Arsandaux.)

2. Suzan, Ariège, 3·2 per cent. $Al_2O_3$ is soluble. 6 per cent. $H_2O$ is given off at 250° C., 9·3 per cent. at 600°, and 10 per cent. at 960° C.

3. Suzan, Ariège, 1·6 per cent. $Al_2O_3$ is soluble. ·6 per cent. $H_2O$ is given off at 250°, 10·7 per cent. at 600°, and 13·2 per cent. at 960°. (M. Blot, see Arsandaux.)

The low $H_2O$ and the soluble $Al_2O_3$ call for remark, as the latter varies very greatly; even in the same locality. It appears to be related to a question of dehydration and crystallisation, the largest percentage of soluble $Al_2O_3$ being found in the newer or less mature parts of a bauxite deposit.

The drainage and railway systems of the area are northward towards Toulouse. A side line, however, runs east from Pamiers to the coast about Narbonne in Aude.

Lacroix gives the following as localities in which bauxite also occurs in this department of France : Pereile, Payreau, Roquefixade, Le Pech de Foix, Le Pech Saint-Sauveur, Coumetorte, Terefort, Cadarcet, Coume Loup Unjat, Suzan Aillères, Clermont, La Barte, Touronand Tauregnan.

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ . . . . . . . | 8·7 | 2·3 | 28·4 | 25·4 |
| $TiO_2$ . . . . . . . | 3·4 | 1·6 | 2·4 | 1·3 |
| $Al_2O_3$ (soluble in HCl) . . | 1·1 | 15·3 | 1·0 | 1·2 |
| $Al_2O_3$ . . . . . . . | 68·8 | 45·8 | 52·7 | 35·1 |
| $Fe_2O_3$ . . . . . . . | 8·4 | 12·2 | ·3 | 25·9 |
| $H_2O$ at 960° . . . . . | 14·1 | 20·7 | 14·3 | 11·2 |
| „ „ 600° . . . . . | 11·4 | 15·6 | 12·3 | 10·0 |
| „ „ 250° . . . . . | ·3 | 6·7 | ·4 | ·5 |
| „ (in matter soluble in HCl) | ·2 | 5·9 | 1·05 | ·99 |

**Bouches-du-Rhône Province.**—The following localities are given by Lacroix for deposits of bauxite: Les Baux, Paradou, Fontvieille, Mausanne, Aureilles, Eygalieres and Orgon, Allauch near Marseille.

The area is well served by roads, railways, and canals. The table at foot of opposite page shows typical analyses from Les Baux by M. Blot for H. M. Arsandaux.

Here again the larger percentage of combined $H_2O$ corresponds with the larger percentage of soluble $Al_2O_3$.

Arsandaux gives further analyses by Blot of bauxite from Gardanne :—

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ . . . . . . | 7·2 | 23·7 | ·8 | 1·1 |
| $TiO_2$ . . . . . . | 1·8 | 1·9 | 3·6 | 3·2 |
| $Al_2O_3$ . . . . . . | 69·2 | 55·1 | 72·8 | 54·5 |
| $Fe_2O_3$ . . . . . . | 8·4 | 3·8 | 9·1 | 30·1 |
| $H_2O$ at 950° . . . . . | 13·5 | 14·1 | 13·9 | 10·4 |
| „ „ 600° . . . . . | 10·8 | 11·6 | 12·3 | 9·8 |
| „ „ 250° . . . . . | ·4 | ·5 | ·6 | ·8 |
| „ (in matter soluble in HCl) | ·6 | 1·2 | ·7 | ·7 |

The low $H_2O$ contents indicate some degree of dehydration, and therefore less likelihood of soluble $Al_2O_3$.

The following are other partial analyses from the same department :—

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ . . | — | 3·0 | 21·7 |
| $TiO_2$ . . | — | — | 3·2 |
| $Al_2O_3$ . . | 52·0 | 60·0 | 58·1 |
| $Fe_2O_3$ . . | 27·6 | 25·0 | 3·8 |
| $Cr_2O_3$ . . | Trace. | — | — |
| CaO . . | — | — | Trace. |
| $H_2O$ . . | 20·4 | 12·0 | 14·2 |

1. Les Baux near Arles (P. Berthier), an immature bauxite with chromium.
2. Les Baux, quoted by Richards.
3. Baux siliceous pink bauxite (Coquand).

Nos. 2 and 3 are obviously dehydrated, and there is no agreement with the formulæ for diaspore, gibbsite, or mixtures of these two hydrates.

**Charente.**—Lacroix mentions Chasseneuil between les Quatres-Vents and le Petit-Madieu in connection with the occurrence of bauxitic material. This area almost borders the Bay of Biscay, and is a long way from Provence.

**Cher (Berri).**—This tract is associated with Indre. It is an isolated area as regards bauxite, being in Central France. Carnot gives an analysis from Bois-de-la-Garenne in Cher, which is quoted by Lacroix and given below :—

| | |
|---|---|
| $SiO_2$ . . . | 11·60 per cent. |
| $Al_2O_3$ . . . | 22·08 ,, ,, |
| $Fe_2O_3$ . . . | 50·87 ,, ,, |
| $H_2O$ . . . | 15·0 ,, ,, |
| $P_2O$ . . . | ·05 ,, ,, |
| $So_3$ . . . | ·40 ,, ,, |

**Hérault.**—Lacroix gives a number of bauxite localities in this department : Villeneuve, Villeveyrac, Loupian, Balaruc, Pierrerac near Saint Chinian, Argelliés, Cazouls, and the environs of Bédarieux.

Augé discusses the excellent red and white bauxites of Villeveyrac. Arsandaux has made use of analyses of the Loupian ore. Laur discusses the suitability of the material from the St. Pargoire tunnel near Villeveyrac for alum manufacture. It is practically the monohydrate of alumina in composition, and easily soluble in $H_2SO_4$ :—

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . . | ·9 | ·9 | 1·9 | 1·90 | ·8 | ·8 | 1·90 | 15·80 | 2·20 | 2·0 |
| $TiO_2$ . . | 1·6 | 2·7 | 1·7 | 3·60 | 2·80 | 3·50 | 1·50 | 1·20 | 4·00 | — |
| $Al_2O_3$ . . | 46·3 | 77·7 | 46·8 | 55·2 | 58·6 | 76·4 | 65·0 | 66·50 | 76·90 | 82·0 |
| $Fe_2O_3$ . . | 38·7 | 2·5 | 38·9 | 25·5 | 26·2 | 4·8 | 17·60 | 2·10 | ·10 | ·10 |
| $H_2O$ . . | — | — | — | — | — | — | 14·00 | 15·20 | 15·80 | 14·2 |
| $H_2O$ at 950° . | 10·6 | 14·5 | 10·20 | 12·4 | 10·9 | 14·3 | — | — | — | — |
| ,, ,, 600° . | 8·9 | 12·5 | 7·6 | 9·7 | 10·3 | 12·5 | — | — | — | — |
| ,, ,, 250° . | ·5 | ·3 | ·6 | ·9 | ·9 | ·4 | — | — | — | — |
| ,, in portion soluble in HCl . | 2·9 | 1·6 | 1·6 | 2·8 | ·6 | ·3 | — | — | — | — |
| Miscellaneous . | — | — | — | — | — | — | — | — | — | 1·70 |

1 to 6. Bauxite from Loupian collected by M. Brongmart. (M. Blot, see Arsandaux.)
7. Red bauxite, Villeveyrac. (Augé.)
8. White ,, ,,
9. From Villeveyrac. (Lacroix.)
10. This from the St. Pargoire tunnel is evidently a less complete analysis quoted by Laur.

All these analyses indicate a certain degree of dehydration, and the variations of the $Al_2O_3$ and $Fe_2O_3$ contents is in agreement with the segregations noticed among tropical laterites in India and elsewhere.

**Puy-de-Dôme (Auvergne).**—Arsandaux gives the analysis of a siliceous bauxite material from Madriat :—

| | |
|---|---|
| $SiO_2$ (30·3 per cent. is free quartz) . . | 57·2 per cent. |
| $TiO_2$ . . . . . . . . | ·6 ,, ,, |
| $Al_2O_3$ (3·0 per cent. is soluble in HCl) . . | 26·9 ,, ,, |
| $Fe_2O_3$ . . . . . . . . | 4·6 ,, ,, |
| $H_2O$ at 960° . . . . . . | 9·6 ,, ,, |
| ,, ,, 600° . . . . . . | 8·3 ,, ,, |
| ,, ,, 250° . . . . . . | ·5 ,, ,, |

**Tarn.**—Tarn lies west of Hérault. Carnot, quoted by Lacroix, gives an analysis of a ferruginous lateritic substance from Brusignol :—

| | |
|---|---|
| $SiO_2$ . . . . | 14·33 per cent. |
| $Al_2O_3$ . . . | 16·00 ,, ,, |
| $Fe_2O_3$ . . . | 53·33 ,, ,, |
| CaO . . . | 1·33 ,, ,, |
| $H_2O$ . . . | 14·67 ,, ,, |

**Var (Provence).**—Sainte Claire Deville gives analyses of bauxite from (1) Revest near Toulon ; and (2) Allauch (Bouches-du-Rhône). As seen below, both are ferruginous :—

| | 1 | 2 |
|---|---|---|
| $SiO_2$ . . . . | 2·80 | 4·80 |
| $TiO_2$ . . . | 3·10 | 3·20 |
| $Al_2O_3$ . . . | 57·60 | 55·40 |
| $Fe_2O_3$ . . . | 25·30 | 24·80 |
| CaO . . . | ·40 | ·20 |
| $H_2O$ . . . | 10·80 | 11·60 |

Arsandaux gives the following analyses by M. Blot :—

| | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|
| $SiO_2$ . . . . . . | ·3 | ·4 | ·9 | 3·6 | 4·2 |
| $TiO_2$ . . . . . . | 2·7 | 2·1 | ·9 | 3·6 | 2·4 |
| $Al_2O_3$ . . . . . . | 81·2 | 82·1 | 66·2 | 71·70 | 43·4 |
| $Fe_2O_3$ . . . . . . | ·5 | ·3 | 19·3 | 1·6 | 23·0 |
| $H_2O$ at 950° . . . . . | 15·0 | 14·8 | 12·4 | 14·8 | 11·1 |
| ,, ,, 600° . . . . . | — | 11·8 | 9·8 | 11·1 | 8·8 |
| ,, ,, 250° . . . . . | — | ·3 | ·4 | ·8 | 1·6 |
| ,, (in portion soluble in HCl) . | ·2 | ·3 | 1·6 | 1·5 | 2·8 |

3, 4, and 5 from Thoronet ; 6 and 7 from La Brasque.

Another interesting set of analyses by M. Blot are given by Arsandaux for the La Caire area (see Nos. 8, 9, 10, 11, and 12) :—

| | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|
| $SiO_2$ . . . . . . | ·29 | 13·3 | 18·2 | 26·7 | 29·3 |
| $TiO_2$ . . . . . . | ·8 | 2·4 | 2·2 | 2·9 | 1·5 |
| $Al_2O_3$ insoluble in HCl . . | 45·0 | 59·8 | 53·9 | 52·6 | 47·7 |
| $Al_2O_3$ soluble in HCl . . . | 15·6 | 3·9 | 4·9 | 1·8 | 2·8 |
| $Fe_2O_3$ . . . . . . | 26·0 | 5·5 | 6·5 | ·3 | 3·1 |
| $H_2O$ at 960° . . . . . | 10·4 | 14·3 | 13·9 | 14·4 | 13·5 |
| ,, ,, 600° . . . . . | 8·1 | 11·2 | 11·2 | 12·2 | 11·6 |
| ,, ,, 250° . . . . . | ·8 | ·8 | ·7 | ·6 | ·2 |
| ,, (in portion soluble in HCl) . | 1·7 | 1·2 | 1·3 | 1·3 | 1·3 |

With regard to the relationship, to which attention has already been drawn, between the percentage of combined water and soluble alumina, No. 8 forms an exception.

Lacroix mentions in addition the following bauxite localities in this department: Le Luc, Cabasse, Vins, Brignoles, Rougiers, Mazaugues, Pourcieux, Ollières, Pourrières, le Val, Aups, Sillans, and Ampas.

The Departments of Var, Bouches-du-Rhône, Gard, Hérault, and Aude, with Tarn and Ariège inland, border the Gulf of Lyons, and have an easy outlet to the sea.

The following extract from the *Mining Journal*, of 5 April, 1924 (p. 275), gives an idea of the changes which are beginning to take place as the result of new discoveries of bauxite in other regions than France:—

> French Bauxite Industry.—Discussing the outlook for French bauxite, a writer in *L'Information* says that 1923 was a very good year from the point of view of exports, foreign buyers having returned to their pre-war suppliers. Production is, however, threatened in several directions. There is the danger of competition from alunite; the United States are steadily developing their production of ore; and there is a further source of competition in the deposits in British and Dutch Guiana. The United States already import some 20,000 tons Guiana bauxite, and as the American imports from France are from 8000 to 10,000 tons, there is a probability of the loss of that market to French producers. There is the more serious possibility that England may decide to replace French bauxite by imports from Guiana, which would provide an excellent return freight for British colliers. Finally, Germany would no doubt be glad to make use of the bauxite deposits in Greece, the turning to account of which has already been reported (*M.J.*, March 29, 1924), in order to become independent of French supplies. These developments, the writer points out, tend to make the future for French bauxite less and less secure, and everything should accordingly be done, not only to extend its employment at home, but also to encourage the export trade by means of low freights and transport charges and up-to-date loading and shipping facilities.

Most of the French exports of bauxite are shipped from one or other of the following ports: St. Raphael, Toulon, Marseilles, and Port de Bonc.

## GERMANY.

Various writers—A. Liebrich, Kobrich, W. Will, H. Munster, etc.—describe the ferruginous bauxites of the Vogelsgebirge of Hesse.

A number of places are mentioned, *e.g.* Stangenrod, Gobelnrod, Harbach, Weickartshain, Garbenteich, Grube Firnwald, Langsdorff, Steinheim E. of Hadamar (50° 28′ : 8° 3′).

Some of the above places are in the Grand Duchy of Hesse, while Steinheim is in Rhine Hesse and Hardamar is in Hesse-Nassau. The German deposits at Bernsfeld, in Hesse, have been worked by the Bauxitwerke Aktien Gessellsschaft of Giessen. The laterite is similar to that of Ireland, and overlies basalt, from the lateritisation of which it has been formed. Analyses are given below :—

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . | 9·78 | 2·3 | 7·45 | 2·8 | 4·6 | 5·14 | 4·92 | 11·0 |
| $TiO_2$ . | — | — | — | — | — | — | 2·80 | — |
| $Al_2O_3$ . | 41·19 | 46·0 | 40·06 | 46·5 | 49·97 | 50·85 | 53·10 | 76·3 |
| $Fe_2O_3$ . | 28·9 | 24·0 | 28·14 | 24·0 | 19·87 | 14·36 | 10·62 | 6·2 |
| CaO . | — | — | — | — | ·58 | — | ·62 | — |
| MgO . | — | — | — | — | Trace. | — | Trace. | — |
| Alkalies . | — | — | — | — | — | ·26 | — | — |
| $H_2O$ . | 19·36 | 28·0 | 22·05 | 27·08 | 24·54 | 28·38 | 27·80 | 26·4 |

1. From Stangenrod. (Kobrick.)
2. ,, Göbelnrod.
3. ,, Harbach. (Kobrick.)
4. ,, Weickartshain. (Kobrick.)
5. ,, Garbenteich, Giessen. (W. Will.)
6. ,, Langsdorff. (Richards.)
7. ,, Grube Firnewald, Giessen. (A. Liebrich.)
8. ,, Steinheim. (Richards.)

It is a significant fact that the older analyses (*e.g.* Richards') show a better quality bauxite than more recent figures. The water percentage is high, and is in agreement with a newer bauxite (or aluminous laterite) than that of the south of France.

The evidence points to a period when the climate of South Germany was tropical. The basalts of the Vogelsgebirge are said to be of Tertiary age, so that the German laterites are also probably of Miocene age.

Details of the German Aluminium Industry will be found in Chapter X. However, in this connection the following extract is of interest :—

> GERMAN ALUMINIUM INDUSTRY.—Discussing the position of the aluminium industry in Germany, the *Journal de Four Electrique* says that the works have been running on a reduced scale, the production of the Lautawerk being at the rate of 200 tonnes, that of the Erftwerk 100 tonnes, and that of the Bitterfeld works 150

tonnes per month. It is suggested that these figures may apply to the closing months of the current year, during which the general industrial situation has gone from bad to worse. For the first seven months of this year imports of raw aluminium and bars are returned at 2916 tonnes, the greater part coming from Switzerland. Exports during the same period amounted to 4675 tonnes, chiefly manufactured material. Statements that German manufacturers had imported large quantities of aluminium bars for working up, to the detriment of home producers, are denied, and it is pointed out that the price of Swiss bars is about 3.25 frs., as against 2.90 frs. quoted by Lautawerk. In German currency the 98-99 per cent. metal was quoted in the home market in September, 84,000,000 marks per kilo, as against 5140 marks at the beginning of the current year (*The Mining Journal*, 1 Dec., 1923, p. 929).

## GREAT BRITAIN: IRELAND AND SCOTLAND.

**Ireland.**—The alumina factory at Larne Harbour was originally erected for the purification of the so-called Antrim bauxite. This material has proved less satisfactory than the bauxite obtained from France. To-day no Irish bauxite is treated in the Larne alumina works. All the low-iron, siliceous bauxite mined in Antrim appears to be disposed of to chemical works manufacturing alum and aluminous salts. The ferruginous bauxite is at present unsaleable. It has not been found suitable for the filtration of kerosene at the Llandarcy Refinery, near Swansea.

The output of bauxite from Ireland has been as follows, and tells its own tale :—

| Year. | Long Tons. | Value £. | Year. | Long Tons. | Value £. |
|---|---|---|---|---|---|
| 1915 . . | 11,723 | 3,163 | 1920 . . | 11,020 | 3,443 |
| 1916 . . | 10,329 | 2,934 | 1921 . . | 2,269 | 477 |
| 1917 . . | 14,724 | 4,132 | 1922 . . | — | — |
| 1918 . . | 9,589 | 2,736 | 1923 . . | — | — |
| 1919 . . | 9,221 | 2,811 | 1924 . . | — | — |

The bauxite or laterite horizon marks a stratigraphical break in the Lower Tertiary basaltic lava flows of North-East Ireland. The upper flows (thought to be uppermost Miocene) are considerably younger than those below owing to a long pause in the eruptions during the Middle Miocene period. During this period the surface of the lower flows was exposed to weathering. The conditions appear to have been suitable for the formation of laterite, but evidently not sufficiently prolonged for the separation of the aluminium hydroxide from the ferric hydroxide and the silica, so as to allow of the segregation of rich masses of true bauxite. The presence of plant beds (a tropical flora) indicate that the partly formed laterite mantle was later the bed of a shallow lake, into which sediments were swept. To this flooding by water, and not by the subsequent lava flows of the Upper Series, must be ascribed the cessation of sub-aerial conditions and the termination of the lateritising processes.

The lenticular nature of the deposits is largely due to the irregularities of the surface exposed to lateritisation during Middle Miocene times. The peculiarities in the composition of the laterite have been largely influenced by the character of the rocks which were lateritised. A certain amount of confusion appears to have been caused by the intrusive dykes and flows of rhyolitic matter, which seem to have been contemporaneous with the formation of the laterite. It is evident, however, that more than one cause prevented the laterite-forming conditions to last sufficiently long to produce bauxite of a quality equal to those of India, British Guiana, or the Gold Coast.

The presence of the overlying series of basaltic lavas renders the "getting" of the Irish bauxite more expensive than would be the case if it could be simply quarried. Most of the best material has to be mined in the same way as a horizontal coal seam.

The first discovery of bauxite was made at Cargan, in the Newton Crommelin area, by J. F. W. Hodges, about 1870, and many of the best mines have been worked in this region—*Skerry*, *Slievenance*, and *Trostan Hill*. The Crommelin Mining Company were actively working at Tuftarney Hill in 1921, and bauxite was also produced from the Essathohan mine, near Parkmore, about the same time. Both bauxite and iron ore used to be worked previously, and it is known that white lithomarge occurs in association with, but below, the laterite zone of this area.

Among other areas in Antrim may be mentioned that of Ballymire and Straid (Irish Hill); also Lyles Hill, near Templepatrick; Shanes Hill; and that of Glenarm, where bauxite is exposed in the scar of Black Hill, and two mines, the Libbert and Cullinane, were formally worked. Bauxite, which lies under a bed of inferior lignite, was also worked at Ballintoy, in the Coleraine area of Londonderry, but no mining has been done for some time.

The following are typical analyses of the Irish bauxite :—

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . | 18·54 | 22·94 | 26·92 | 8·67 | 12·00 | 10·40 | 9·36 | 11·04 | 24·50 |
| $TiO_2$ . | 1·61 | 1·61 | 7·94 | 5·80 | 6·20 | 4·20 | 7·20 | 2·56 | 9·40 |
| $Al_2O_3$ . | 50·50 | 44·79 | 36·90 | 53·83 | 52·00 | 46·13 | 48·57 | 57·32 | 45·42 |
| $Fe_2O_3$ . | 3·34 | 6·30 | 4·15 | 1·57 | 4·57 | 15·14 | 11·63 | 0·24 | 1·54 |
| CaO . | — | — | — | 0·62 | 0·79 | 0·18 | — | 0·61 | 0·46 |
| MgO . | — | — | — | 0·13 | 0·20 | 0·26 | — | 0·36 | Trace. |
| $Na_2O$ } $K_2O$ } | — | — | — | 0·01 | 0·08 | 0·28 | — | 0·17 | 0·04 |
| $SO_3$ . | — | — | — | 0·07 | 0·07 | 0·10 | — | 0·30 | 0·08 |
| $H_2O$ . | 26·03 | 24·37 | 20·23 | 29·27 | 24·00 | 23·39 | 21·75 | 27·16 | 18·53 |

(*For description of columns see following page.*)

1. Lower Bed, light coloured. Tuftarney Hill.
2. ,, ,, dark coloured. ,, ,,
3. ,, ,, average. ,, ,,
4. First quality. Irish Hill.
5. Second ,, ,, ,,
6. Third ,, ,, ,,
7. Lyles Hill.
8 and 9. Cullinane.

The above analyses are of considerable interest, in that they show, by the high silica content, arrest of the lateritising processes. The high titanium dioxide percentage is very similar to the analyses of Indian bauxites, which are in most cases also the residual weathering products of basaltic lavas. The presence of sulphur is curious and probably indicates the presence of iron pyrite in the original basalt, or it may have been introduced from the material of the overlying sedimentary beds.

The geology of Antrim has been dealt with by numerous writers : G. G. Blackwell, G. A. J. Cole, G. H. Kinahan, F. R. Mallet, W. Peile, C. H. Williams, R. Tate, and J. S. Holden. Of these perhaps the most important are : *Mem. Geol. Survey, Ireland*, 1912, " Interbasaltic Rocks of N.E. Ireland " ; and *Mem. Geol. Survey, Ireland, Min. Res.*, 1922, " Memoir and Map of Localities of Minerals of Economic Importance and Metalliferous Mines in Ireland " : both by G. A. J. Cole.

### SCOTLAND.

G. V. Wilson (see " The Ayrshire Bauxitic Clay," *Mem. Geol. Surv., Scotland*, 1922, p. 28), while working in Ayrshire, discovered a remarkable horizon of aluminous clay. He traced it from the sea coast at Saltcoats to as far as Kilwinning, and recognised it in various places—Lugton Water, Annick Water, Fenwick Water, and near Kilmarnock, also near Stranraer and on Arran. The following review of Mr. Wilson's report expresses the opinion I formed after visiting the area between Saltcoats and Kilwinning (*The Mining Journal*, 10 March, 1923, pp. 194-195) :—

> " In this pamphlet of only 28 pages, Mr. Wilson, of the Geological Survey of Scotland, has put together some very valuable information. He shows that the strata, which he describes as ' bauxitic clay,' can be traced throughout the North Ayrshire coalfield, and states that the same horizon has been recognised in the island of Arran to the west, and near Stranraer to the south. Mr. Wilson recognised the commercial value of the substance, and during the war recommended its use as a high-grade refractory for special purposes. He must feel great satisfaction in knowing that his suggestions were immediately followed up, and that a small industry is now in process of growth as a result of his labours.
>
> " The material in question is a non-plastic fire-clay, with an exceptional percentage of alumina. It averages (near Saltcoats, Raise Road exposure) 44·0 per cent. alumina, 36·24 per cent. silica, 4·45 per cent. titania, 1·08 per cent. ferric oxide, with roughly 14·08 per cent. combined water in the Saltcoats-Kilwinning area. Further east, near Kilmarnock, the quality is poorer, an average analysis (Fenwick

water sample) being 34·67 per cent. alumina, 41·68 per cent. silica, 6·10 per cent. titania, 3·52 per cent. ferric oxide, with about 13·53 per cent. combined water. In Arran and elsewhere the quality is not so good. Some samples of the Saltcoats area (from Glebe quarry) are said to have resisted, without fusion, temperatures of 1800 to 1850 ° C. (above Seger Cone No. 36, old scale). The normal average, however, appears to be about Seger Cone No. 32.

"This 'bauxitic clay' occupies a horizon at the top of the Millstone Grit series of Ayrshire, Arran, and Wigtownshire, and is overlaid by the lowest seam, the Raise Coal, of the Coal Measures of this part of Scotland. The bed of bauxitic clay is evidently associated with an important series of basaltic lava flows, which are interbedded with fire-clays, coaly layers, and gannister beds. These strata are again underlaid by the well-known Moncastle clay and a thick bed of sandstone. The last-named bed overlies a thin zone of shales, with occasional fossil-bearing calcareous bands.

"The official opinion, as expressed by the author, is that the 'bauxitic clay' represents the residual weathering product of the basalt. The lava flows are thought to have been exposed to atmospheric influences previous to the deposition of the overlying Coal Measures of the Carboniferous period. It is presumed that during this 'stratigraphical break' the physical and climatic conditions prevailing were the same as those which result in the formation of laterite to-day. These assumptions have largely influenced Mr. Wilson in the choice of the word 'bauxitic,' although he gives the definition of the term on a chemical basis (see p. 6 of the memoir). With this definition we are not in agreement, more particularly as the author uses the term 'siliceous' for clays where there is an excess of silica (after that required to form kaolinite with the alumina present). It would, therefore, be logical and preferable to use the term 'aluminous' when there is an excess of alumina in a clay.

"The term 'bauxitic' is objectionable on other grounds. We do not think the case for the existence of laterite-forming conditions during the Millstone Grit period has been proved. The geographical conditions during this volcanic epoch of the Carboniferous period favours the presence of lagoons and marshes, due to a gradual uplift of a sea-floor of an earlier stage of the same period. The presence of a marked geological unconformity between the Millstone Grit and the overlying Coal Measure series is not convincing in this part of Scotland. The striking continuity of this highly aluminous clay horizon, together with its large silica and low iron content and general fairly uniform composition over a wide area, is suggestive of another mode of origin than that given by Mr. Wilson. Remembering that the strata are associated with carbonaceous beds, it is reasonable to presume that the original basalt might have become decomposed, and then leached of its iron contents, by percolating waters carrying carbonic or even organic acids which had been obtained from the coal seams above. The example we have in mind is described in the *Records of the Geological Survey of India*, vol. xliv, part ii, 1914, pp. 123 to 136. In this instance a basalt dyke at Barkui Colliery, Chhindwara District, Central Provinces, has been converted into a cream-coloured lithomarge where it is in contact with the coal. The least altered portion of the dyke has the following composition: Silica, 36·95 per cent.; titania, 3·05 per cent.; alumina, 17·88 per cent.; ferric oxide, 5·84 per cent.; ferrous oxide, 12·12 per cent.; magnesia, 5·45 per cent.; lime, 3·39 per cent.; combined water, 6·14 per cent.; and moisture, 6·99 per cent. The white portion of the dyke has the composition: Silica, 40·84 per cent.; titania, 2·68 per cent.; alumina, 32·13 per cent.; ferric oxide, 2·21 per cent.; ferrous oxide, 1·05 per cent.; magnesia, 0·90 per cent.; lime, 2·64 per cent.; combined water, 10·14 per cent.; and moisture, 9·06 per cent. It is evident that this lithomarge is almost identical in composition with that of the Ayrshire aluminous clay. The process is not quite complete, but the reactions have not been in operation so long as in the case of the Ayrshire strata—the Indian dyke being of Upper Cretaceous to Eocene age, as against the Carboniferous age of the Scotch lavas.

"It may be of interest at this point to reconsider the meaning of the term 'bauxite.' Berthier's analysis of the substance, which was subsequently called bauxite, contained 52·0 per cent. alumina, 27·6 per cent. ferric oxide, 20·4 per cent. combined water, and only a trace of silica. It was practically a mixture of the hydroxides of aluminium and ferric iron, and was characteristically free of silica. Analyses of bauxite from France, Italy, Dalmatia, Rumania, India, West Africa, Guiana, and the United States, average 50 to 70 per cent. alumina, 0 to 25 per cent. ferric oxide, and 10 to 30 per cent. combined water, but may contain up to 10 per cent. silica and occasionally up to 10 per cent. titania (see *The Mining Magazine* for February, 1922). It is seldom economical to use bauxite containing more than 5 per cent. silica as an ore for aluminium (see commercial specifications of bauxite given in *The Mining Journal* of 30 December, 1922). The term bauxite has consequently been applied to the highly aluminous laterite which is used as a raw material by producers of metallic aluminium.

"For the reasons given above, it is evident that the term 'bauxitic' for the aluminous clays of Ayrshire is not appropriate, nor is the wider term lateritic applicable. Neither on chemical nor on the physical grounds advanced has Mr. Wilson justified his use of the term bauxitic. He has much to prove. The question of pisolitic structure does not affect the case very much, as there are well-known occurrences of pisolitic or oolitic limestones, siliceous material, and ironstones, which are certainly not bauxitic. We have rather laboured this point regarding the term bauxitic, but questions of nomenclature are very important when a name suggests mode of origin.

"No criticism of terminology can diminish the valuable properties of the material which Mr. Wilson has so ably described. Its remarkable heat-resisting properties have already attracted considerable attention. The fact, proved by Mr. Wilson, that an Ayrshire brick, when long exposed to working conditions, becomes a felted mass of sillimanite is most interesting (see photo-micrograph), in view of the article on sillimanite which we are publishing on another page. The introduction of an inferior plastic clay, however, lowers the heat-resisting properties of this Scotch clay, and this difficulty of making up furnace goods, bricks, etc., with a suitable binder has yet to be solved."

## GREECE.

Damour mentions the occurrence of a lateritic bauxite on the summit of Mount Agios, in the island of Aegina, and of a similar substance as occurring in the island of Naxos in the Grecian Archipelago.

The following extract is taken from *The Mining Journal* of 29 March, 1924, page 251 :—

*L'Echo des Mines* publishes a note from the Greek Geological Bureau on the subject of the bauxite deposits situated in the Distomo (Bœotia) region. They are met with (1) on the western slopes of Mount Colovricos, favourably situated within easy access of the sea the (thickness of this deposit, which is already being worked open cast, varies from 1 metre to 3·5 metres) ; (2) at Karayanni-Vrissi, with a thickness of 2·5 metres ; (3) at three points on the eastern slopes of Mount Xerovouni, all three deposits being interesting from the point of view of tonnage, and favourably situated for transport ; (4) on the eastern slopes of Kastri-Distomo, to the west of the Levadia-Distomo main road ; (5) at Vayona, on Mount Aghios ; (6) near Arachova. After analysis conducted by the Geological Bureau, the mineral was classified among the red bauxites, the tenour in alumina being given as 54·35-57·53 per cent. $Al_2O_3$, and that of silica 3·84-3·62 per cent. $SiO_2$. The appearance of the outcrop in the Levadia-Distomo zone suggests the possibility of the existence of bauxite in other parts of Greece. A detailed study of the mineral is about to be carried out by the Bureau from a geological and a chemical point of view.

G. W. Rumbold (*Bauxite and Aluminium*, 1925, p. 80) quotes the following analyses, which were made by the Greek Geological Bureau, of bauxite associated with beds between Lower and Upper Cretaceous age, near Distomo village :—

| | | |
|---|---|---|
| Silica . . . . . . | 3·84 | 3·64 |
| Titania . . . . | 0·18 | — |
| Alumina . . . . . | 54·35 | 57·53 |
| Ferric oxide . . . . | 18·95 | 22·80 |
| Lime, Magnesia, and $S_2O_5$ . | 5·90 | 2·24 |
| Loss on ignition . . . | 17·24 | 14·01 |

## HUNGARY.

According to information communicated by Dr. Ladislas Szabo, of Budapest,

> "There are two considerable bauxite fields in Hungary : the one around the northern shores of the great Lake Balaton, between the villages Szöc and Halimba ; the other in the Vértes mountain, between the towns Csákvár and Csákberény. Both the quantity and the quality of the ore deposits are highly satisfactory ; Government figures estimate about 30,000,000 tons of bauxite ore to be found there. The starting of a great aluminium industry would be, therefore, within the limits of a sound speculation, and the by-products of the aluminium industry would be of great benefit to the already existing chemical and ceramic industries of the country" (*The Mining Journal*, of 28 Mar., 1925).

No analyses are given, but the discovery appears to have received considerable attention in Hungary, for

> "According to *Finanzobserver* of Sept. 22, the researches made by the Hungarian National Geological Institute have led to the discovery of bauxite in a very shallow depth on an area of about 500 cadestral jochs on the hilly land between Bakony and Vertes forests. It is a pure ore, which can be used for the production of aluminium. For the exploitation of this bauxite field a joint stock company has already been founded, and includes foreign capital. Two factories are to be erected by the company for the production of aluminium" (*The Mining Journal*, of 3 Oct., 1925).

## ITALY.

C. Formanti, G. Aichino, D'Achiardi, Lotti, Novarese, M. Gortani, Martelli, Martirolo, Salmoiraghi, R. E. Vinassa de Regny, and E. T. T. Taramelli describe the terra rosa and give analyses of bauxite from the Central Apennines.

The areas mentioned are in the vicinity of Lecce dei Marsi in Aquila (Abruzzo) ; Pescosolido in Liritale of the Bez Sora region, and Piedmonte d'Alife near Dragone, both in the Terra di Lavoro Province of Campagna ; and about Pietraroja and Cusano Mutri along the Metese mountains of the Neapolitan Apennine of Benevento in Campagna. In Northern Italy bauxite occurs in the newly acquired territory of Istria south of Trieste, and also east of the Isonzo River on the slopes of the Julian Alps.

**Abruzzo.**—Avezzano (a railway junction west of the paludine tract of Fucino), is connected across the Apennines with Sora, and finally with Naples by rail. The first section of this line passes through the bauxite areas of South Abruzzo and N.W. Terra di Lavoro. It is equally far from the Abruzzo deposit by rail to the port of Pascara, north of Aquila. The following analyses show the type of material likely to be met with :—

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $SiO_2$ . . | 2·33 | 2·79 | 5·98 | 2·85 | 3·05 | 3·86 |
| $TiO_2$ . . | 2·86 | 1·27 | 1·39 | 2·55 | 2·44 | 2·24 |
| $Al_2O_3$ . . | 47·44 | 57·60 | 43·41 | 57·52 | 55·01 | 53·26 |
| $Fe_2O_3$ . . | 36·37 | 26·55 | 35·53 | 21·68 | 24·29 | 26·74 |
| CaO . . . | ·38 | — | ·70 | ·20 | ·58 | ·59 |
| MgO . . | ·41 | — | — | ·39 | ·25 | ·39 |
| Moisture . . | ·84 | — | 1·73 | — | — | — |
| $H_2O$ combined . | 10·17 | 11·71 | 10·97 | 13·30 | 12·72 | 11·37 |
| $SO_3$ . . | — | — | ·14 | — | ·015 | ·017 |
| $P_2O_5$ . . | ·02 | — | — | — | — | Trace. |
| Corundum . | — | — | — | 1·46 | 2·54 | 2·16 |

1. Leece dei Marsi. (Mattirolo.)
2. „ „ (Aichino); dark red, pisolitic bauxite.
3. „ „ (C. Formanti). (G. D'Achiardi.)
4. Pink bauxite, Monte Turchio.
5. Red „ „ „ (C. Formanti.)
6. Pink „ „ „ „

From these analyses it is seen that the iron percentage is high, and the percentage of combined $H_2O$ low, indicating dehydration. These aluminous laterites are probably of the same age as those of Yugo-Slavia and France, *i.e.* early Eocene.

**Campagna.**—The following analyses of the bauxites of Terra di Lavoro and Benevento are very similar to those already given, and the same remarks apply in general with regard to these :—

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_3$ free . . | — | 2·52 | — |
| $\left.\begin{matrix}SiO_2\\TiO_2\end{matrix}\right\}$ . . . | 7·91 | 1·27 | 6·87 |
| $Al_2O_3$ . . . | 58·85 | 58·40 | 56·53 |
| $Fe_2O_3$ . . . | 18·62 | 24·12 | 24·88 |
| FeO . . . | — | ·71 | — |
| CaO . . . | ·30 | — | ·25 |
| MgO . . . | ·37 | — | Trace. |
| $H_2O$ . . . | 13·27 | 13·11 | 11·08 |
| $H_2O$ (moisture) . | ·87 | — | — |

1. Bauxite from Pietraroja, Benevento. (Mattirolo.)
2. „ „ Pescosolido, Bez Sora. „
3. From Ricca di Mezzo.

**Calabria.**—Messonier gives the following analysis for a ferruginous bauxite or laterite from Calabria, which has been quoted by Deville and Coquand, but the occurrence is disputed by Salmoiraghi :—

| | |
|---|---|
| $SiO_2$ . . . | 2·0 per cent. |
| $TiO_2$ . . . | 1·6 ,, ,, |
| $Al_2O_3$ . . . | 33·2 ,, ,, |
| $Fe_2O_3$ . . . | 48·8 ,, ,, |
| CaO . . . | 5·8 ,, ,, |
| $H_2O$ . . . | 8·6 ,, ,, |

**Carniola.**—In the country east of the Isonzo valley, and on the northern slopes of the Julian Alps, there are bauxite deposits in the vicinity of Lake Wochein, near Feistritz.

This used to be the Austrian province of Carniola. The actual location of the deposits with regard to the international boundaries, as arranged by the Peace Conference after the Great War of 1914-1918, appears to be partly in Italy and partly in the neutral corridor of the Adriatic. Nos. 1 and 2 of the following analyses of wocheinite or bauxite from the Wochein area are in general similar to the early Eocene variety of Croatia. No. 3 is different, and is more in agreement with some of the more recent Indian types :—

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ . . | 4·15 | 4·25 | 6·29 |
| $Al_2O_3$ . . | 63·13 | 72·87 | 64·24 |
| $Fe_2O_3$ . . | 23·55 | 13·49 | 2·40 |
| CaO . . | — | — | ·35 |
| MgO . . | — | — | ·38 |
| Alkalies . . | ·79 | ·78 | Trace. |
| $H_2O$ . . | 8·34 | 8·50 | 25·47 |
| $CO_2$ . . | — | — | ·20 |
| LiO . . | — | — | Trace. |
| $P_2O$ . . | — | — | ·46 |

1. Dark earthy bauxite. (J. W. Richards.)
2. Light ,, ,, ,,
3. Bauxite. (Fleckner.) All are from near Feistritz.

A railway connects Feistritz with Gorizia, Morifalcone and Trieste

**Istria.**—Bauxite is reported from the coast region of the peninsula of Istria (Kustenland). No definite localities are given, but the railway southward from Trieste to Rovigno and Pola passes through the bauxite area. The Bauxit Aktien Gesellschaft of Budapest are working on the islands of Veglia, Arbe, Goli, and S. Gregario. The Montan Bergbau Gesellschaft of Vienna and Trieste own some of the deposits of Monte Kahin.

The real Italian interests are represented by the Sindicato Italiano Miniere per la Venezia Giulia.

Unfortunately no analyses have been available for comparison. The area, however, is probably related to those of Carniola and Croatia, as part of the land surface exposed by the regression of the Mediterranean Sea at the close of Cretaceous times.

## MONTENEGRO.

"According to the *Deutsche Bergwerks Zeit.*, a large deposit of bauxite has been discovered between Bar and Ulcin, in Montenegro. The deposit is stated to be of a character similar to the Hungarian bauxite deposits, and in quantity it is estimated to contain 30,000,000 tons. The nearest port is in the Bay of Mrkovac, which is about 9 kilometres from the deposit. The occurrence has already been extensively explored by Herr Körner, a well-known Vienna geologist. A concession has been obtained provisionally by a local firm, but negotiations are stated to be in progress with both French and German interests for the exploiting of the deposit."

*The Mining Journal*, 5 December, 1925, p. 957.

## YUGO-SLAVIA OR GREATER SERBIA.

All the areas in which bauxite occurs in the Balkans were given to Yugo-Slavia after the Peace Settlement of the Great War of 1914-1918. Croatia and Dalmatia both originally belonged to Austria-Hungary.

This area is part of the north Adriatic area which includes Istria and Carniola. There was a *break* in this region at the close of the Cretaceous period, and it was a land area early in Eocene times. It would appear that the climate of this area at that date was tropical and subject to monsoon conditions.

Bauxite is found in the hills bordering the Adriatic. In the Velebit Mountains of Dalmatia, at Studenovzelo and Mortar in Bosnia, and Badujévaés, Kragujevácz in Serbia. There are papers on the subject by Kispatic, F. Tucan, G. Stache, W. Graf zu Leiningen, F. Katzer, and E. Kramer.

**S. Croatia.**—Analyses are available for the bauxite of the following areas: Mazin, Rudopolge (near Bruvno), Skoćaj, Grgin, Vratce (4 kilometers south-west of Gràčac (Grachatz), and from Zupanjac (near Eminoselo). There are estimated to be over a million tons of bauxite in the deposits near Gràčac.

It is a very difficult and somewhat inaccessible country. The most direct outlet is over the Yelebieh Geb to Zara in Dalmatia. The easier way is south-east to the railhead of Knin, which communicates with Sebenico.

Several analyses are given below :—

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 27·36 | 10·14 | 14·72 | 10·29 | 8·04 | ·37 |
| $TiO_2$ | Trace. | Trace. | ·86 | — | — | 8·51 |
| $ZrO_2$ | — | — | ·41 | — | — | ·45 |
| $Al_2O_3$ | 48·13 | 60·53 | 56·30 | 50·61 | 60·99 | 55·43 |
| $Fe_2O_3$ | 16·28 | 16·87 | 13·51 | 26·89 | 17·62 | 21·78 |
| CaO | — | ·30 | ·79 | Trace. | — | — |
| MnO | Trace. | Trace. | Trace. | Trace. | 1·07 | — |
| $H_2O$ | 8·68 | 12·56 | 13·05 | 11·29 | 11·78 | 13·46 |

1. Mazin, Crojtia. (Kispatic).
2. Rudopolae, near Bruvno, Croatia. (Kispatic.)
3. Skoćaj, Croatia. (Kispatic.)
2. Rudopolje, near Bruvno, Croatia. (Kispatic.)
4. Grgin, Croatia. (Kispatic.)
5. Vratce, 4 km. south-west of Grachatz. (Kispatic.)
6. Zupanjac, Bosnia. (Kispatic.)

Tucan gives two analyses of a substance which is highly calcareous and with 30 per cent. $SiO_2$. This is neither laterite nor bauxite, and is not given here.

All the above analyses show the effects of dehydration by their low percentage of combined $H_2O$. These agree very well with the Rumanian type, but are more siliceous and less ferruginous. The presence of $ZrO_3$ is of interest. These variations in composition are evidently indicative of original differences in the rock which has been lateritised. Although the cumulative effect of the lateritisation processes towards the elimination of all substances except $Al_2O_3$ and $Fe_2O_3$, some of the more insoluble substances remain with the lateritic constituents.

**N. Dalmatia.**—The bauxite tract is south of Knin and in the vicinity of Dernis.

Kispatic gives analyses from the following localities : Bistrica, Drnis, Hvar, Kljake, Mosec, and Obrovac :—

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 61·31 | ·89 | 30·47 | 27·32 | ·87 |
| $TiO_2$ | Trace. | — | — | Trace. | — |
| $ZrO_2$ | Trace. | — | — | 2·71 | — |
| $Al_2O_3$ | 16·95 | 51·85 | 29·05 | 24·54 | 59·27 |
| $Fe_2O_3$ | 12·46 | 26·82 | 16·24 | 20·09 | 24·36 |
| CaO | — | — | 6·79 | 6·40 | — |
| MgO | — | — | Trace. | — | — |
| MnO | Trace. | 1·21 | Trace. | Trace. | — |
| $H_2O$ | 6·40 | 19·97 | 17·14 | 18·77 | 5·93 |

*(For description of columns see following page.)*

1. Siliceous laterite from Bistrica, Dalmatia. See Kispatic. Analysis by Tucan.
2. Drnis, Dalmatia. See Kispatic. Analysis by Tucan.
3. Hvar (Milna), Dalmatia. See Kispatic. Analysis by Tucan.
4. Kljake, Dalmatia. See Kispatic. Analysis by Tucan.
5. Mosec, Dalmatia. See Kispatic. Analysis by Tucan.

The laterites are all somewhat abnormal, except Nos. 2 and 5. They may possibly represent true detrital laterites. The $H_2O$ percentage is somewhat higher than in the Croatian type, so that it is quite possible that these laterites may be of recent geological age: the evidence of the analyses points to their being detrital material. Tucan gives a number of analyses of laterite from the following places: Obrovac, Grobnickopolje, Jelenje, Karlobag, Plase, and Zlobin. In general, they are similar to the analysis of the material from Kljake, *i.e.* large percentages of $SiO_2$ and $Fe_2O_3$, appreciable traces of $ZrO_2$ and MnO, and evidence of CaO.

## RUMANIA.

The whole area in which bauxite is found belonged originally to Hungary, but has been handed over to Rumania as a result of the Peace Conference after the Great War of 1914-1918. All the deposits occur in the Bihar mountains, and some have been described by Horvath, R. Lachmann, J. Szadeczky, and S. Gyulatol.

From the analyses given below it will be seen that the substance is somewhat ferruginous. It occurs on Triassic and Jurassic rocks, and appears to be of about the same age as the great salt deposits of Transylvania. If this is correct, these laterites mark the break between the close of Cretaceous times and the Tertiary epoch, and are of Eocene Age. This is in agreement with the contraction of the great Mediterranean Sea of that period.

There is little information available regarding the quantity of aluminous laterite of bauxite quality. The following localities are given as places of occurrence: Cucul, Décisko, Dealul Popii, Dealul Cruci, Rev, Mnierei, and Ponoras. Communications are poor. The analyses are as below:—

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ . . | 1·49 | ·8 | ·8 | 1·4 | 1·0 | 1·0 | 2·88 | 1·54 |
| $TiO_2$ . . | 3·12 | 2·8 | 3·2 | 2·7 | 2·0 | 2·0 | 3·68 | 3·07 |
| $Al_2O$ . . | 59·66 | 65·5 | 53·7 | 53·4 | 56·20 | 58·81 | 44·25 | 63·27 |
| $Fe_2O_3$ . | 23·66 | 21·3 | 29·7 | 30·8 | 29·0 | 26·65 | 23·05 | 20·34 |
| $H_2O$ . . | 11·81 | ? | ? | 11·4 | 12·0 | 12·0 | 11·43 | 11·62 |

1. From Cucul. (Lachmann.)
2. Dealul Cruci. ,,
3. Rev. ,,
4. Dealul Cruci. ,,
5. Cucul Cruci. (Lachmann.)
6. Dealul. ,,
7. Ponoras. ,,
8. Mnierei. ,,

There are certain remarkable features in the above analyses. The exceedingly low percentage of combined water is an indication of dehydration. Such a substance would, if its physical properties were satisfactory, appear to be eminently suitable for the purification and decolorisation of petroleum. Unfortunately it is possibly not a true laterite, and its porosity may prove too small for such uses. It is of a composition that would make firebricks and the refractory linings of steel furnaces. It is reported (*Engineering*, 16 Aug., 1918, p. 163) that 1,000,000 tons of Hungarian bauxite are said to occur in the Galbina Valley and in the districts of Petrosz and Sykerisora of S. Biharhegység, while 350,000 tons are reported from Iádvölgy in the N. Biharhegység ; 12,000,000 tons are estimated in Bihàrmegyei Kiralyerdö, and 7,000,000 tons in Possieior Hodisanuln.

## RUSSIA.

It is difficult to obtain reliable data with regard to the reported bauxite discoveries in Russia. Two extracts (1925) in this connection are appended :—

ALUMINIUM ORE IN RUSSIA.—*Moscow*, May 28.—The *Ost Express* says that, according to official economic reports, investigations in connection with the aluminium ore discovery near the River Tshussovaya (Government of Perm) have proved the existence of considerable quantities of bauxite and aluminite. Exploring work is being continued, and the production of aluminium will begin shortly.—(*Reuter.*)

BAUXITE DEPOSITS IN RUSSIA.—*Moscow*, June 29.—The Geological Committee has completed its investigation of the material obtained in connection with the Tikhvin bauxite deposits, in the department of Novgorod, not far from Leningrad. It appears that from these deposits might be obtained 11 to 12 million poods (177,430 to 193,560 tons) of aluminium and a large quantity of bauxite clay, a valuable material for the manufacture of mineral paints.—(*Reuter.*)

The bauxite occurrences of the Wolozsba River are said to have been discovered in 1882, but received no attention until the Great War (W. G. Rumbold, *Bauxite and Aluminium*, 1925, p. 85).

A scientific examination of specimens of a diaspore type of bauxite from the Urals has been carried out by N. S. Kurnakov and G. G. Urazov (*Anal. Phys.-Chem.*, Leningrad, 1924, 2, pp. 496-498), but no economic questions are discussed.

## SPAIN.

The following particulars are taken from *Bauxite and Aluminium* (Imp. Inst. Monograph, 1925, pp. 85-86), by W. G. Rumbold :—

“ Bauxite is reported to occur near Gijon in Asturia, Spain, but few particulars are available. The following are analyses of two samples of this material :—

ANALYSES OF SPANISH BAUXITE.

| | No. 1. Per Cent. | No. 2. Per Cent. |
|---|---|---|
| Alumina | 51·64 | 44·50 |
| Silica | 10·87 | 16·80 |
| Cupric oxide | 0·63 | 0·83 |
| Lime | 0·16 | 0·60 |
| Water | 36·60 | 35·95 |

"These analyses indicate material exceptionally free from iron, which should make it useful for the manufacture of aluminium chemical compounds. The small proportion of copper in the ore probably would not prove a difficulty.

"The bauxite deposits of Catalonia have been described by P. H. Sampelayo (*Bol. del Inst. Geol. de España*, 41, 1920). The area in which they occur covers 31 square miles in the S.W. zone of the Province of Barcelona. The deposits can be described as a scattering of small outcrops, related to fractures, and without stratification. The bauxite as a rule occurs with nodules in clay found in marls, sometimes alternating with gypsum or in limestone, and in places distinctly pisolitic. The largest deposit (Rubio outcrop) hitherto found is 100 to 130 feet long, 10 feet high, and 40 feet wide, in limestone. A sample analysed gave the following percentages: Alumina, 48·52; ferric oxide, 18·80; silica, 18·30; titanic dioxide, 1·37; loss by ignition, 11·93.

"The bauxites of Catalonia are believed to be of Lower Eocene age, and of hydrothermal origin, although most probably laterisation has occurred at certain points. The percentage of silica in them is high, so that at present the bauxite can be used only for obtaining aluminium sulphate, or as a refractory, or, locally, as a building stone.

"Some of the deposits were first opened up in 1918. The production of bauxite in 1918, 1919, and 1920 amounted to 453, 1751, and 531 long tons respectively. There has been none since." (*The Mineral Industry During* 1922, p. 31, 1923.)

# CHAPTER VII.

## THE MINING, PREPARATION, AND MARKETING OF BAUXITE.

**Quarrying and Mining Bauxite.**—The method of extracting bauxite from a deposit varies with the mode of occurrence of the ore. In France the bauxite occurs interbedded with beds of Upper Cretaceous age. The outcrops can frequently be quarried by means of open pits, but when the bauxite bed dips away to appreciable depths the material has to be mined in the same way as coal or other bedded deposits. Much of the bauxite in the Department de Var (France) is mined like gently inclined coal seams, *i.e.* by driving two inclines to the dip and connecting these at intervals by means of levels in which the actual mining is carried on. Occasionally the bauxite bed is steeply inclined, and necessitates the procedure, of shafts and levels with overhand and underhand stoping, in vogue in metal mines, and a good deal is quarried in a normal manner. The bauxite of Co. Antrim (Ireland) is worked in very much the same way as the French ore, except that workings are all on the level, owing to the fact that the bauxite occurs as an aluminous laterite interbedded with the horizontally bedded basaltic lavas of Ulster. The bauxite occurrences of Italy, Dalmatia, etc., and the Balkan area in general, has so far been won by simple quarrying by hand, but in the last-named region, particularly in Rumania, it appears that mining will have to be resorted to.

In the United States of America the mode of occurrence of the bauxite is somewhat different to that of the deposits of Europe (Mediterranean). The Arkansas bauxite consists of a gently inclined ore bed about 11 feet thick, which is overlaid by loose sandy clay. The outcrop was cleared and quarried, but now the working requires the removal of from 25 to 140 feet of overburden. This useless, soft covering is normally removed by steam shovels. In some cases the steam shovel is unable to strip the entire depth of waste material, and, as it is important to keep the bauxite as free as possible from impurities, the last few inches of the overburden are removed by hand, and the surface of the bauxite swept clean of rubbish. Recently, however, the cost of removing the overburden has resulted in the deposits either being closed or mined. In Georgia, Alabama, and Tennessee the ore occurs in irregular pockets, which involve working by open pits. Some ores are harder than others, and may require the use of explosives. When the ore body or bed lies in undulating country it is often possible to get over water difficulties by cutting drainage channels, otherwise pumping must be resorted to in the usual way.

PHOTOGRAPH X.

[*Per favour: Trade Commissioner for British Guiana in London.*

Quarrying Bauxite, loading ore, British Guiana.

In British Guiana the bauxite at present being worked is exposed on the surface of the ground, and merely requires digging out. The same is true for the bauxite occurrences of West Africa and India.

In the latter country the greater number of bauxite deposits occur as segregations in the laterite which caps flat-topped hills and plateaux. These occurrences can, of course, be worked and kept free of water with little difficulty. There are localities in India (*e.g.* Surat) as in other countries, where bauxite occurs under loose material in low ground or interbedded with more massive strata. Such cases will require exploitation in one or other of the ways already discussed in connection with the bauxite of Europe or America. The removal of overburden or dewatering of workings naturally increases the cost of the raw material, but these factors may be offset by the favourable location of the deposit to a railroad or waterway.

Dr. T. Poole Maynard, in *Bauxite and Aluminium*, says of the mining methods of the United States :—

> The engineer who for the first time observes bauxite mining in the Appalachian Valley field would be amazed to see clays and low-grade bauxites carted away in wheelbarrows, the ore mined by pick and shovel, and raised from these funnel-shaped openings by skips and aerial cableways. Although the deposits are above water level, the large V-shaped pits are usually drained by pumps, and during rainy seasons these pits are " loblollys," and the cost of mining made prohibitive, due in part to the nature of the deposits and in part to natural human tendencies where there is a monopoly of anything.
>
> It is evident from what has been said about the bauxite deposits that :—
>
> (1) The present methods of mining are wasteful. Many bauxite mines have been abandoned, it proving unprofitable to work many deposits of low-grade, or even win the high-grade ores on account of the large number of clay " horses," or the proportion of clay to bauxite being greater than could be worked profitably by hand methods.
> (2) That in any event only the mines most favourably located with relation to transportation and overburden, or deposits of high grade, could be worked profitably on account of the high cost of mining.
> (3) Large deposits of low-grade bauxites of 45-50 per cent. alumina-content have not been considered of commercial interest.
> (4) Independent corporations have been kept out of the field on account of the practical impossibility of getting sufficient tonnage of bauxite to warrant commercial development other than on a very small scale.
> (5) The development of the industries dependent upon bauxite for their raw material has been retarded by the lack of confidence of capital that they could be assured a supply.

**Treatment of Low-Grade Bauxite.**—In many cases it has been both possible and profitable to wash certain ferruginous bauxites, and by getting rid of a large percentage of the heavy hydrated ferric oxide, obtain a concentrate with a high alumina content. This mechanical treatment of low-grade ores has been in use in several of the bauxite-containing areas in the United States for many years. The machinery utilised has so far been some simple washing device, such as log washers, etc., which have not been as successful in getting rid of the siliceous matter in the ore as the ferruginous impurities. Other mechanical devices, such as jigs, concentrating tables, etc., have also been utilised successfully, but these elaborate appliances are not as cheap as the washers, and are only used in special cases.

A great deal of attention was recently paid to the Everhart process for concentrating low-grade bauxite. The process is discussed as follows by Dr. T. Poole Maynard :—

> The alteration of clays into bauxite ordinarily has been so gradual that the slight distinction in the two materials imposes great difficulty in their separation in the process of concentration. In the study of many bauxitic clays, Dr. Edgar Everhart has demonstrated that this physical difference is sufficiently marked, however, to allow of satisfactory separation by washing in the presence of small amounts of added peptizers. This makes possible the recovery of bauxite from two types of deposits hitherto not considered of commercial interest, namely, first those deposits carrying both granular high-grade ore and mixed with varying grades of low-grade ore, where the proportion of clayey impurities varies from as low as 2 to 1 to where the proportion of clay to bauxite is as much as 7 to 1.
>
> The result on this type of ore is as follows :—
>
> | Crude Ore. | | Concentrated Ore. |
> |---|---|---|
> | 48·87 | Alumina ($Al_2O_3$) | 57·85 per cent. |
> | 24·39 | Silica ($SiO_2$) | 11·60 „ |
> | 2·94 | Iron oxide ($Fe_2O_3$) | 1·76 „ |
> | 2·13 | Titanium dioxide ($TiO_2$) | 2·13 „ |
>
> The second type of deposits made available are the so-called low-grade bauxites and bauxitic clays carrying from 45-52 per cent. alumina, which are not now considered of commercial value, but which can be concentrated to from 55-58 per cent. alumina, with a loss of clayey impurities varying from 25-45 per cent.
>
> Bauxites from a wide range of localities have been tried out by this process. The most successful commercial peptizers used are sodium hydroxide and the more strongly absorbed sodium salts. Patents have been granted covering the use of the above materials and process. A curious phenomenon observed in connection with these experiments is that in a few of the highly aluminous clays sulphuric acid, which usually acts as a coagulant, appears in the role of a peptizer in certain low concentrations. Another feature of very great commercial importance is that the iron and titanium oxides contained in the clay substance are not precipitated with the alumina, but are washed out with the clayey impurities. This makes available for the chemical industries as well as for the manufacturer of aluminium an ore high in alumina and at the same time very low in iron and titanium.
>
> The use of this process does not involve any particular type of machinery. It can be adapted to the wide variety of washing and concentrating machinery now on the market, dependent entirely on local conditions. As this process of concentrating bauxite is the converse of the present system of clay washing, the clays can very readily be recovered in the refined condition and used in suitable by-products. Extensive tests have shown that this means of concentration can be applied with success to a wide variety of low-grade bauxites in the three great fields in this country. While certain indurated and more silicious ores are not susceptible to treatment, there remains a broad field of application.
>
> The use of these methods can make possible the use of mechanical equipment in mines, save much of the wasted overburden, and make commercial many of the underlying bauxitic clays, thereby making available the immense deposits so low in alumina that they have never been opened.

**Calcination of Bauxite.**—It has previously been shown that raw bauxite contains from 10 to over 30 per cent. of combined water. As most bauxite requires transportation over considerable distances to the place where it is utilised, it has become customary, particularly in the United States, for large producing companies to effect economies on freight. This is done by getting rid of some or all of the combined water by drying, partial or complete calcination of the ore (see *Eng. and Min. Jour. Press*, Nov. 4, 1922, p. 807). In Arkansas the American Bauxite Company dumps the ore from the

PHOTOGRAPH XI.

[*Per favour: Trade Commissioner for British Guiana in London.*

Steamer loading Bauxite, British Guiana.

mine cars into large bins, from the bottoms of which it is removed by pan feeders. Hard rock is fed to large gyratory crushers, and the soft ore to disintegrators of a special type. From the crushers horizontal and inclined-belt conveyors collect the ore, elevate it, and distribute it to large storage bins. From the bins the ore is fed by gravity directly to a battery of ten rotary kilns. The kilns are 50 feet long, and most of them are cylindrical, 7 feet in diameter. A few 6-feet cylindrical kilns, and a few tapered kilns, 6 to 8 feet and 7 to 10 feet, are also used. These kilns were once fired mostly by producer gas, but they have been converted to burn pulverised coal exclusively. The temperature used is probably about 1100° F. (roughly 600° C.), and the mechanically held moisture is reduced to from one-half of 1 per cent. to 1 per cent. From these kilns the material drops into a long pan conveyor, where it cools to some extent, and is then elevated into large bins. For shipment the ore is drawn off through chutes into covered, hopper-bottom, standard-gauge railway cars of a special type. The bauxite from British Guiana is also calcined and, from reports, those of Dutch Guiana will be similarly treated before export.

**Classification of Bauxite.**—Although it is known that there are many types of bauxite, it is not sufficiently recognised that there are two distinct classes of ore. The two main classes are: (1) The French or Mediterranean " terra rosa " type; and (2) the Indian or " laterite " type. Under the former class are included the bauxites of the Appalachian region of the United States, Spain, France, Italy, Yugo-Slavia, and Rumania—types which in Europe seldom contain more than 14 per cent. of combined water, and indicate a certain degree of dehydration. The latter class includes most of the bauxites of America (Arkansas), Africa, India, and Australia. These deposits appear to be of a geologically younger type, and average a combined water content of from 22 to 30 per cent., with a somewhat lower, 54 per cent., alumina content than the Mediterranean type.

For commercial purposes it is convenient to classify bauxites into the following varieties:—

(*a*) *Normal Bauxite.*—Fair quality, with 55 to 60 per cent. alumina and high-grade ore with over 60 per cent. of alumina. Total impurities not to exceed 20 per cent., excluding the combined water content. The chief impurities: ferric oxide, silica, and titania, each not to exceed 5 per cent.

(*b*) *White or Siliceous Bauxite.*—To have upwards of 55 per cent. alumina, and not more than 20 per cent. impurities, excluding the combined water. The silica varies from over 5 to about 20 per cent.; ferric oxide less than 5 per cent., titania up to 5 per cent. This class of ore is most frequently used for chemical purposes for the preparation of alum and other aluminium salts.

(c) *Titaniferous Bauxite.*—The alumina to average 55 per cent., and the total impurities, excluding combined water, not to exceed 25 per cent., titania above 7 per cent., silica less than 5 per cent., ferric oxide not to exceed 10 per cent. These bauxites are rare except in India, but have a great future before them, owing to the valuable nature of the titaniferous slime which can be obtained as a by-product when the ore is purified by the Bayer process.

(d) *Red or Ferruginous Bauxite.*—Alumina content to be upward of 52 per cent. Total impurities not to exceed 25 per cent., ferric oxide between 10 and 25 per cent., silica to be less than 5 per cent., titania normally less than 5 per cent. This variety of bauxite is most commonly used by aluminium reduction companies.

(See *The Mining Journal* for 30 Dec., 1922, p. 986.)

There would thus appear to be eight varieties of bauxite, but these would merge, with calcination, into the four commercial varieties detailed above.

A lengthy scientific classification of bauxite has not been considered necessary, as it is to be remembered that the term " bauxite " applies to the ore of aluminium, and consequently it is the economic and not the scientific classification which is desirable. Dr. L. L. Fermor and Professor Lacroix have very ably discussed the classification of laterite. As stated previously, bauxite is now considered to be a highly aluminous type of laterite.

**Bauxite Specifications and Contracts.**—For many years the principal use of bauxite has been for the preparation of alumina, and the subsequent reduction of this substance to aluminium. In a subsidiary way bauxite of a certain quality has been utilised in the chemical industry, and some bauxite has been absorbed in the production of alundum and other purposes. The chief users have usually possessed or leased bauxite properties, so that there has been little or no buying and selling of bauxite in the open market. During the last decade, however, a considerable degree of attention has been devoted to the development of bauxite properties which are not under the control of monopolistic consumers. This has come about by the increasing demand for bauxite. There has not only been an expansion of the aluminium industry, but because bauxite has been found useful for the purification of petroleum and other oils, and a new field has opened with the successful manufacture of so-called bauxite (high alumina) cements. In these circumstances it may be of interest to those who are prospecting and opening up bauxite occurrences in our overseas dominions to know the general lines on which bauxite is at present being bought and sold.

It may elucidate matters if the principles adopted in the marketing of other ores are first briefly stated. There are two methods in use, both of which depend on the percentage of the chief constituent required in a given ore. As examples, chromite, graphite, and molybdenum ore belong to one class, while manganese ore, monazite, and wolframite (tungsten ore) come under the other class. In the former class the ore is sold by weight, usually the ton, depending on the grade or quality of the material. Thus chromite with over 48 per cent. of chromic oxide ($Cr_2O_3$) nominally fetches prices of from £3 10s. to £6 per ton c.i.f., U.K. port; graphite of from 80 to 85 per cent. purity is quoted at roughly £12 a ton, London; molybdenum ore carrying 85 per cent. molybdenum sulphide ($MoS_2$) sells at about 3s. a lb. (since 1915 it has been the practice to quote molybdenum ore per unit of 22·4 lb.). The ores of the other class are sold per unit content of the desired constituent, with the stipulation that this constituent is present in more than a certain minimum percentage. Thus manganese ore, with not less than 42 per cent. manganese (metal), is quoted at (for Indian ore) about 15d. per unit of metal present; monazite concentrates are available for from £5 to £6 per unit of thoria ($ThO_2$) for material averaging 9 to 10 per cent. thoria; wolfram has been offered for about 14s. per unit of $WO_3$ for ore containing upwards of 60 per cent. $WO_3$. All these are London prices. An approved independent chemist is usually asked to umpire for both buyer and seller in both classes of ore, and his analyses are accepted in estimating the total value of a shipment.

In the case of bauxite, one or other of the two methods stated above are adopted. Much, however, depends on the quality of the ore and the purpose for which it is required. Aluminium reduction companies will seldom accept bauxite with more than 5 per cent. silica, although they have been known to take delivery of ore with as much as 20 per cent. ferric oxide. Chemical works do not refuse bauxite containing 10 per cent. of silica if the alumina content is high and the ferric oxide percentage below 3 per cent. They seldom accept ore with more than 5 per cent. ferric oxide. Manufacturers of abrasives, while demanding the best grades of normal bauxite, often utilise ore with less than 50 per cent. alumina, and more than 10 per cent. silica, or 15 per cent. ferric oxide. Makers of furnace refractories stipulate that the ferric oxide content must be low, but may accept bauxite with as much as 25 per cent. silica. In some cases they prefer to use a material so rich in silica that it can scarcely be called a bauxite. Investigators in oil refineries do not yet know, with any exactness, the type of bauxite most suited to their use.

Certain normal Indian ores have been found to desulphurise and decolorise petroleum very effectively, but have not been equally efficient with petrol or heavy oils. The purification of petroleum and other oils is evidently effected by the physical (colloidal) properties of the bauxite rather than by chemical action, and in consequence of this it is at present impossible to judge the value of a bauxite for this purpose on its chemical composition alone. Experiments in the production of high alumina cements (ciment fondu, etc.), although showing the commercial importance of the finished product, have not yet proved that one type of ore is more particularly desirable than another, provided the alumina content is high.

All consumers would probably be willing to accept somewhat inferior qualities of ore at advantageous prices if the composition of the material can be guaranteed within certain agreed narrow limits. It is the practice of most consumers to partially calcine the raw bauxite before finally grinding it to dust or slime. This calcination, usually performed at a temperature not exceeding 400° C., drives off a considerable amount of the combined water, and gets rid of any organic matter which may be present. It also converts ferrous oxide into the more manageable ferric oxide. The alumina content is naturally increased by this calcination; but it is not to be forgotten that the percentage of the impurities is also raised. Raw bauxite is notoriously variable in composition, and in large occurrences it is advisable to sample and analyse the deposit very thoroughly. It is possible by mixing known qualities of bauxite from various parts of a single large deposit, or from more than one deposit, to maintain shipments of uniform quality. In this way, if due attention is paid to the sampling and chemical analysis of bauxite, it is probable that considerable quantities of low-grade ore could be mixed with particularly rich material. By so doing, otherwise unmarketable low-grade ore might be the saving of a pocket bauxite only rich in patches. The importance of having the services of an efficient chemist available will become more apparent when we come to deal with the specifications and contracts of alumina and aluminium.

The following methods of analysis adopted by certain important assayers and consumers of bauxite are a valuable indication of the procedure in use. The details have been very kindly supplied by the firms mentioned.

[*Copy.*]

### I.—ANALYSIS OF BAUXITE.[1]

The sample is ground to an impalpable powder.

Two grams are mixed with about 12 grams pure anhydrous sodium carbonate and a little sodium nitrate, and fused in a platinum crucible for 30 to 45 minutes, or until all action has ceased.

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[1] W. T. Scales & Co., Ltd., Cleveland Works, Birkenhead.

The fused mass after cooling is treated in a covered beaker with excess of diluted HCl, and kept in a warm place until completely disintegrated.

The liquid is then evaporated to dryness in a porcelain basin on a water bath, then heated on a sand bath, and after cooling treated with a little strong HCl, being then allowed to stand in a warm place for about 1 hour. Hot water is then added and the liquid filtered. This treatment with HCl being repeated twice, the residue consisting of $SiO_2$ is washed with boiling water, dried, burnt off, and weighed.

The filtrate is made up to 500 c.c.

200 c.c. (equal 0·8 grams of sample) are boiled with a few drops of $HNO_3$ to oxidise the iron, excess of ammonia is added, the whole filtered and washed once. The precipitate, together with filter paper, being transferred to a porcelain basin, is dissolved in HCl, diluted and reprecipitated with excess of ammonia, the precipitate, consisting of $Al_2O_3$, $Fe_2O_3$, and $TiO_2$, being washed, dried, burnt off, and weighed.

To the filtrate is added excess of ammonia oxalate, the precipitate (if any) being filtered, washed, dried, burnt off, and gently ignited as usual, the lime being weighed as $CaCO_3$.

*$TiO_2$.*—20 c.c. of the solution (equals 0·08 grams of sample) is placed in a Nessler glass, 1 c.c. of Hydroxyl added, and made up to 50 c.c., the colour of this solution being matched by adding to a similar Nessler glass the necessary quantity of a standard solution of $TiO_2$ containing 0·001 grams $TiO_2$ per c.c., and 1 c.c. of Hydroxyl, and made up to 50 c.c.

*$Fe_2O_3$.*—1 c.c. of the solution (equals 0·004 grams of sample) is mixed with 1 c.c. of a solution containing ·25 grams potassium sulpho-cyanide per c.c., and the colour compared with that of another solution made by adding the necessary quantity of a standard solution of iron containing 0·00001 grams Fe per c.c., the weight of Fe so ascertained being calculated into $Fe_2O_3$.

The percentage of $TiO_2$ and $Fe_2O_3$, ascertained as above, are then deducted from the percentage of $Al_2O_3$, $Fe_2O_3$, and $TiO_2$, the balance being $Al_2O_3$.

*Moisture.*—10 grams of the sample are heated in the water-bath till weight is constant. Loss equals moisture.

*Loss on Ignition.*—1 gram is heated in platinum crucible over Bunsen burner until weight is constant, the loss, less moisture, equals loss on ignition.

[*Copy.*]

### II.—Analysis of Bauxite.[1]

Moisture is estimated by drying a weighed portion at 100-110° C. to a constant weight. "Loss on ignition" (= combined water, organic matter, etc.) is determined by heating a weighed portion over a Bunsen burner until the organic matter is burnt off, and, finally, for 20 or 30 minutes at full heat of the blast lamp, and weighing as rapidly as possible, as calcined $Al_2O_3$ is definitely hygroscopic.

*For $Al_2O_3$, $Fe_2O_3$, $SiO_2$ and $TiO_2$.*—Take 4 grams of the finely ground sample (moisture free) and extract with 30 c.c. of 50 per cent. $H_2SO_4$ and 2 c.c. pure HCl (not quite to complete dryness). This may be carried out conveniently in a basin of platinum or fused silica of about 60 c.c. to 70 c.c. capacity covered with a watch-glass, and standing in an ordinary 6-inch diameter porcelain basin which is heated by a very low Argand Bunsen flame. The outer vessel will retain anything that may be ejected from the small inner basin, and in a few hours the extraction will be finished. Then cool and cover again with 10 c.c. of 10 per cent. $H_2SO_4$ and 10 c.c. pure HCl, gently heat to boiling, when dissolved wash into a larger vessel, dilute to say, 100-200 c.c., filter, and wash insoluble, using warm (not hot) water. The insoluble residue is incinerated, then wetted with a little strong sodium bisulphate solution and fused up, in platinum or fused silica, with a few grams of sodium bisulphate at red heat for 20 minutes. The fusion vessel should be fairly large (about 300 c.c.) to allow room for frothing, which usually occurs at first, and a glass cover is useful for observation.

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[1] Peter Spence & Sons, Ltd., Manchester Alum Works, Manchester.

Add to the cooled fusion in the crucible 100 c.c. of 10 per cent. HCl, replace the cover and gradually heat to the boil, and keep hot until the cake has dissolved. Cool, and wash out with cold water into a basin or beaker, and filter on the vacuum filter—giving the insoluble silica seven or eight small washes. Ignite and weigh the *insoluble matter*, which is mainly silica. To obtain the actual silica ($SiO_2$) treat with pure HF and a drop of $H_2SO_4$, take to dryness, ignite at a red heat, and re-weigh.

Make the combined filtrates and washings up to 1000 c.c. Take 200 c.c. and boil with a little nitric acid to oxidise the iron, cool to about 60-70° C., precipitate the bases with a *slight* excess of ammonia, boil a few minutes, filter, wash six times, re-dissolve in HCl, re-precipitate with ammonia, and wash free from $SO_2$, ignite, and weigh the precipitate, which contains the $Al_2O_3$, $Fe_2O_3$ and $TiO_2$.

*For $Fe_2O_3$.*—Take 500 c.c. and exactly oxidise the iron with $\frac{N}{10}$ permanganate, add, say, 2 or 3 grams KCNS as indicator, and titrate to just colourless with titanous chloride solution. The titanous chloride is standardised with pure ferric sulphate (iron ammonia alum) before use.

*For $TiO_2$.*—Take 250 c.c., add 100 c.c. strong HCl, and boil gently for 20 minutes on excess of clean lead shot in a flask fitted with valve to exclude air. Pour the reduced solution off the lead shot, wash the latter quickly three or four times with cold distilled water, add KCNS to the mixed liquor and washes, and titrate, while still warm, with standard ferric sulphate solution till a faint red colour remains.

The $Fe_2O_3$ and $TiO_2$ subtracted from the $Al_2O_3$, $TiO_2$, and $Fe_2O_3$ gives the $Al_2O_3$.

[*Copy.*]

### III.—CHEMICAL ANALYSIS.[1]

For your information, the methods we adopt for the determination of alumina, ferric oxide, silica, and titanic acid, and which we have found to give very accurate results, are outlined as follows :—

(*a*) Direct fusion of the mineral with pure bisulphate of potash, solution of the melt in water, and separation of silica by filtration (with purification by hydrofluoric acid and correction for presence of alumina, ferric oxide, and titanic acid). The titanic acid is separated from the filtrate by precipitation with sulphurous acid, ignited and weighed, with subsequent fusion and colorimetric determination to check the gravimetric result.

The total iron oxide and alumina are obtained pure by repeated precipitation with ammonia, the iron being determined by titration with bichromate, and the alumina taken by subtracting this result from the weight of combined oxides.

(*b*) Results obtained by the above process are checked by direct treatment of the bauxite with sulphuric acid, removal of silica, etc., etc.

If required, "free" and "available" alumina are determined, and also moisture, combined water, organic matter, etc.

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[1] Messrs. Pattinson & Stead, Laboratory and Assay Office, 11 Queen's Terrace, Middlesborough.

[*Copy.*]

### IV.—CHEMICAL ANALYSIS.[1]

In reply to yours of February 23rd, regarding bauxite, the following is the method we generally follow :—

> Sample is fused with NaOH, melt extracted with hot water and filtered. Insoluble residue contains all $TiO_2$ and $Fe_2O_3$. The filtrate is acidified and evaporated to dryness to remove $SiO_2$ in the usual way. Residue taken up with dilute acid, filtered $SiO_2$ burnt off and weighed, and $Al_2O_3$ determined in filtrate in the usual way. (If phosphate is present it is first removed in usual way.) The insoluble residue is dissolved in concentrated HCl, the bulk of the free acid boiled away, and nearly all the remainder neutralised. Excess of $Na_2S_2O_3$ is then added, and the liquor boiled to precipitate $TiO_2$, which is collected and weighed. The iron in the filtrate is then estimated volumetrically.

We trust this rough indication of the methods we use will be of service.

## SALE CONDITIONS.

The following general sale conditions (taken from the latest edition of *Traité Général de Commerce des Minerals, Metaux, etc.*, by Robert Pitavel) are recommended :—

**France.**—*White Bauxite for Chemical Purposes.—First Quality*—Alumina, 60 per cent. minimum, at 1 fr. per unit of $Al_2O_3$ ; 3 per cent. ferric oxide, with right of refusal if $Fe_2O_3$ exceeds 3·5 per cent., and an allowance in favour of buyer of 0·4 fr. for each tenth of 1 per cent. $Fe_2O_3$ above 3 per cent. These are prices f.o.b. port of embarkation. Prices f.o.r. at station of despatch are about 10 frs. less per ton (1000 kilograms) than the f.o.b. price. For a quality with less than 2 per cent. $Fe_2O_3$ the price per ton is 4 frs. higher.

*Second Quality.*—Alumina, 57 per cent. minimum ; ferric oxide, 4 per cent. maximum. Price, f.o.b. port of embarkation, per ton (1000 kilograms), 54 frs. Price, f.o.r. station of departure, 44 frs.

*White Bauxite for Refractory Purposes.*—Alumina, 50 per cent. to 60 per cent. ; and ferric oxide, 3 per cent. to 4 per cent. Price, f.o.b. port of embarkation, 52 frs. per ton of 1000 kilograms ; f.o.r. station of departure, 42 frs. per ton. If ferric oxide up to 2 per cent. maximum, f.o.b. price per ton is 56 frs. and f.o.r. price 46 frs. If ferric oxide content does not exceed 1 per cent., f.o.b. price is 59 frs. and f.o.r. price is 49 frs.

*Red Bauxites Low in Silica.*—Alumina, 56 per cent. to 60 per cent., 50 frs. per ton of 1000 kilograms, f.o.b. Mediterranean port, with a premium of 0·2 fr. to 0·4 fr. per unit of $Al_2O_3$ above 60 per cent., and right of refusal if $Al_2O_3$ is less than 55 per cent. Silica not to exceed 3 per cent., with a premium of 0·2 fr. for each tenth of 1 per cent. below 2 per cent. Ferric oxide, maximum 17 per cent., unless higher percentage is permitted, with a penalty of 0·2 fr. for each per cent. above 14 per cent. The f.o.r. prices station of departure are 10 frs. less per ton on the calculated f.o.b. price.

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[1] Stockton-on-Tees Chemical Works, Ltd., Bowesfield Lane, Stockton-on-Tees.

*Payments for Deliveries in France.*—By rail: Draft in thirty days from the end of the month of delivery, without discount. By sea: 80 per cent. against bill of lading in sender's drafts, the balance immediately after receipt of goods in a new draft; the whole net discount. Payment by cheque on Paris.

*Payments for Deliveries Abroad.*—By rail: Draft in 30 days from the end of the month of delivery, without discount. By sea: 80 per cent. against bill of lading, the balance immediately after receipt of goods at the port of unloading; the whole net discount.

*Weight to be Paid For.*—For rail transport: Weight on the trucks at the station of departure. No reduction for moisture unless above 5 per cent. For sea transport: Weight stated in the despatch bill of lading. No reduction for moisture unless above 5 per cent.

*Analyses.*—Sampling by both parties at time of despatch. Analysis of material dried at 100° C. In case of disagreement, expert analysis at the expense of both parties.

**Great Britain.**—The aluminium companies in this country own bauxite concessions in the south of France, and consequently would seldom purchase bauxite in the open market unless the quality was better than the French ore, or the prices asked were considerably less than those at which the French bauxite is available at Larne, Burntisland, or Newcastle-on-Tyne.

Chemical companies, however, are prepared to buy bauxite at about 1s. per unit of alumina when total alumina is above 60 per cent. and the ferric oxide is less than 3 per cent. and does not exceed 5 per cent. If the ferric oxide is less than 2 per cent. they would pay a premium of 1½d. to 2d. per tenth of a unit of ferric oxide. If the ferric oxide exceeds 3 per cent. they would deduct 1½d. to 2d. per tenth of a unit of ferric oxide, and refuse a shipment with more than 5 per cent. The maximum silica allowed is 10 per cent. If the alumina content averages from 55 per cent. to 60 per cent., and the ferric oxide does not exceed 4 per cent., the price is roughly £2 10s. per ton c.i.f. U.K. port. For a low ferric oxide content a higher price, about £3, may be obtained. If the ferric oxide exceeds 3 per cent., but is less than 5 per cent., the price will be about £2 per ton.

The terms of business are the same as in most other ores and raw materials, *i.e.* part payment against bill of lading and remainder on arrival of ore at port of unloading. If the bauxite is offered f.o.b. port of embarkation the price must be arranged between buyer and seller under the usual guarantee of quality. Payments are preferably made on London. The weight paid for will include 5 per cent. for moisture as distinct from combined water.

**United States.**—Alumina, 52 per cent. minimum ; ferric oxide, 2 per cent. maximum ; silica, 20 per cent. maximum, with not more than 4 per cent. moisture—average price at mine, $10 per ton (2000 lb.). Alumina, 54 per cent. minimum ; ferric oxide, 2 per cent. maximum ; silica, 15 per cent. maximum ; and 5 per cent. moisture—roughly, $11 per ton at mine. Alumina, 57 per cent. minimum ; ferric oxide, 3 per cent. maximum ; silica, 8 per cent. to 12 per cent. ; moisture not exceeding 8 per cent.—$13 per ton at mine. It will be seen that these are white bauxites for chemical purposes. Bauxites of higher grade alumina and low in silica command special prices. The normal bauxites for aluminium reduction purposes are seldom quoted in the open market, as the Aluminium Company of America controls its own bauxite workings. The terms of sale appear to be part payment on despatch and remainder on receipt of ore at station of unloading.

**Ore Contracts.**—(See *Traité Général de Commerce des Minerals, Metaux, etc.*," by Robert Pitavel.) Agreements regarding ore contracts and similar matters are usually arranged by private negotiation. The items invariably included as clauses in such agreements are for (1) quantity ; (2) quality ; (3) price ; (4) insurance ; (5) freight ; (6) weight ; (7) declaration of shipment ; (8) sampling and analysis ; (9) loss or transhipment ; (10) payments ; (11) accidents ; and (12) arbitration. The following specimens of agreements for contracts and freight may serve as examples :—

### I. Specimen Agreement.

An Agreement made this day of , 19 , between their heirs, executors administrators and assigns (hereinafter called " The Buyer ") of the one part, and of $\frac{\text{his}}{\text{their}}$ heirs, executors, administrators and assigns (hereinafter called " The Seller ") of the other part, whereby it is mutually agreed as follows :—

1. The Seller shall sell and the Buyer shall purchase the undermentioned
Ore at the price of Rs. per Ton Free on Rail at
to be delivered between the and
by

2. The Buyer shall pay for all Ore delivered into waggons either in cash or by cheque on at Buyer's option on or before the 10th day of the month immediately succeeding the month in which delivery thereof shall have been made. The amount payable shall be calculated on the actual net Railway weight of the ore as ascertained by weighment thereof on the Railway Company's weighbridges. If from any case whatsoever the Buyer shall be prevented from procuring a supply of Railway waggons to allow of equal quantities of ore being railed each month the Buyer shall pay to the Seller on or before the date aforesaid per cent. of the estimated value of the ore delivered and stacked ready for railing, but not railed during the preceding month, and shall pay the balance of the

price of the ore upon the same being railed and the actual weight thereof being ascertained in manner aforesaid.

3. The Seller guarantees that the percentage of in the dry in all ore delivered under this contract shall not be less than per cent. The Buyer shall be entitled to reject all ore in which the percentage of in the dry shall be less than per cent., and ore so rejected shall not be reckoned in the quantity to be delivered to the Buyer under this contract.

4. The Buyer shall be entitled to draw samples from time to time from all ore delivered under this contract for the purpose of analysis, and if as a result of any analysis made by the Buyer the percentage of in the ore shall be found to be less than per cent., fresh samples shall be drawn by Buyer and Seller jointly and sealed and submitted for analysis to an independent analyst, mutually agreed, or failing agreement to any Government Analyst whose analysis shall be final and binding upon both parties. The cost of such independent or Government analysis as the case may be shall be borne by the Seller if the percentage of shall be found to be less than per cent.; otherwise by the Buyer.

6. The Buyer shall be entitled to supervise the loading of the ore into Railway trucks, and to wash the ore and remove all stones, quartz, and foreign matter found therein.

6. The Seller shall grant to the Buyer an allowance of one per cent. for loss in moisture and during transit.

7. If from any cause beyond Seller's control, the Seller shall be unable to complete deliveries of the contract quantity of Ore within the contract period, the Seller shall be at liberty to deliver against such undelivered quantity Ore of the same quality as the contract quality, but raised from other mines belonging to or controlled by the Seller.

*Quantity and Description of Ore.*—(Here may follow the agreed bonus or penalty per unit and per ton for above or under the agreed percentage, and penalties per unit and per ton over agreed minimum percentages of silica and phosphorus.)

Seller's Signature. Buyer's Signature.

Witness. Witness.

## II. Specimen Contract Note.

Contract for the sale and purchase of Indian Ore made this day between the referred to herein as the "Sellers" and referred to herein as the "Buyers," on the following terms and conditions :—

Quantity.— tons.

Quality.—Mineral from the Sellers' Mines.

Price.— Pence per unit of per ton, nett c.i.f. Docks, with per ton allowance from the Sellers to Buyers if delivery is made at .

Freight.—Freight to be paid by buyers in cash, in the usual way, after arrival of steamer at port of destination, and balance of final invoice in cash in thirty days after date of final discharge.

Shipment.—

Discharging as customary.

Sampling.—By two samplers, as usual, one acting for Buyers and one for Sellers. Sampling to take place during the discharge of steamer at port of destination.

Analysis of the sample so taken to be made by Messrs. of , whose results shall be final and basis of invoice.

Moisture.—As ascertained by analysis to be deducted from the weight as customary.

Weight.—Invoice to be based on weight delivered at port of destination, as ascertained by the Railway Co. if at Docks, or by the if at . It is understood that neither Buyers nor Sellers shall be held responsible for any delay in the execution of this contract, owing to the act of God, war, plague, pestilence, famine, strikes, interference to transport or shipment, perils of the sea, or any other incident or accidents beyond their control.

Should steamer carrying ore under this Contract be lost, Sellers are to take steps to replace the quantity so lost with as little delay as possible, consistent with their other obligations contracted previous to the knowledge of such loss.

(Signed)

Accidents.—The Sellers are not held responsible for delay in despatch or delivery in cases where they are prevented by wars, military operations, strikes, disease, or the usual accidents of the sea, etc., in fact, practically any circumstances outside the Sellers' control.

### III. Specimen Contract for Cost, Insurance, and Freight.

We have this day by your order and for your account, upon the terms of the printed Rules of the General Produce Brokers' Association of London, as endorsed hereon,

The following Goods, viz.

About
at
per Cost, Freight and Insurance, weights.

Insurance.—To be insured $\frac{\text{with particular average}}{\text{or free of particular average}}$ at the price of this Contract.

Shipment.—To be shipped during the months of by Steamer or Steamers from to direct, $\frac{\text{and}}{\text{or}}$ indirect, with liberty to call $\frac{\text{and}}{\text{or}}$ tranship at other ports; but if to France, no transhipment West of Port Said, except at a French port, or by *force majeure.*

Guarantee of Quality.—To be , or if inferior, a fair allowance to be made. The same to be settled by arbitration, such arbitration to be demanded within twenty-eight days, and held within six weeks after the arrival of the Vessel.

Weight.—The Goods to be weighed at Buyers' expense at the port of discharge named in the Contract, or duly declared by the Buyers according to the Contract; and Buyers shall furnish, where sold on delivered weights, as soon as possible, a properly certified copy of landing weights. Each shipment, if by more than one Vessel, and each mark or counter mark to be treated separately.

Declaration of Shipment.—The name of the Vessel or Vessels, marks, and full particulars to be declared to the Buyers in writing with due despatch.

Sampling.—If to ports other than London, samples to be drawn and sealed in the presence of representatives of Buyers and Sellers, or if in London, by the Port of London Authority or Wharfingers, and forwarded to selling Brokers in London. Failing Sellers naming their representatives on or before arrival of Vessel, the Buyers' accredited sealed samples to be accepted.

Loss or Transhipment.—Should the Vessel or Vessels which may apply to this Contract be lost before declaration, this Contract to be cancelled, so far as regards such lost Vessel or Vessels on the production of the Bill or Bills of Lading, or other satisfactory proof of shipment, by Sellers, so soon as fairly practicable after the loss is ascertained.

Should the Vessel or Vessels, after declaration, and the Goods or any portion thereof be lost, this Contract to be cancelled for the whole or such portion (as the case may be) unless the Goods shall have been previously paid for, but should the Vessel or Vessels be lost and the Goods or any portion thereof be transhipped to some other Vessel or Vessels, and arrive on account of the original Importer, this Contract to stand good for such portion.

Payment.—Cash against documents in London or on (at Buyers' option) or before arrival of Vessel or Vessels at port of discharge. But in no case later than the due date of Sellers' draft. Rebate at Current rate of Interest allowed by Eastern Banks in London for unexpired portion of Shippers' sight draft.

Arbitration.—Any dispute arising out of this Contract to be settled by Arbitration in London in the usual manner, according to the Rules of The General Produce Brokers' Association of London.

Brokerage, per cent., ship lost or not lost.

*Brokers.*

## IV. Specimen Freight Agreement.

*Freight Agreement.*

Between Messrs. of London, Disponents of the Steamer (classed 100 A1, or a class equal thereto), of the one part.

And Messrs.

Charterers, of the other part, for the shipment of a part cargo or part cargoes of Ore.

Loading Port.—To be Loaded as customary at

Destination.—To be Discharged as customary at

Quantity.—Quantity to be not less than tons, and not more than tons in Disponents' option.

Shipment.—Shipment to be made in one or more bottoms at Disponents' option.

Freight.—Rate of Freight to be shillings and pence ( ) per ton of 20 cwt. nett weight delivered. Freight to be paid in cash, without discount, to , on arrival, and adjusted on the unloading and right delivery of the cargo as customary.

Notice of Readiness.—Twenty-four Hours' Notice of readiness in each case is to be given to Shippers' Agents at loading port, after which time to count unless work commenced earlier.

Separation of Cargo.—If any Ore other than that of Present Charterers be shipped, same is to be kept separate at Disponents' expense. If present Charterers ship more than one quality of Ore, same is to be kept separate by the Steamer at Charterers' risk and expense.

Night Work.—Steamer is to Work at Night if requested by Charterers, and to give use of cranes and winches with necessary steam power and hands, Charterers paying all extra expenses of such night work.

A commission of on the freight is due on shipment to Messrs.

Signed this day of , 192 .

*Disponents.* *Charterers.*

# CHAPTER VIII.

## THE USES OF BAUXITE.

### Preparation of Bauxite.

Comparatively little, less than one-third, of the bauxite produced from the various quarries and mines in America, France, etc., is used directly in the several industries for which the raw material is obtained. The greater proportion, over 60 per cent., of the world's output of bauxite is treated for the extraction of the pure aluminium hydroxide (or aluminium oxide) which it contains. Of the several processes which have been utilised, the one most frequently employed is that known as the Bayer (or Wet) process. Probably 90 per cent. of the alumina or aluminium hydroxide produced to-day is obtained by the Bayer process. The Deville-Pechiney, Peniakoff, and Griesheim-Elektron processes, and quite recently the Serpek process, are being chiefly employed for the preparation of the remainder of the alumina produced from bauxite, as distinct from the alumina extracted from clays, felspar, leucite, or similar aluminous substances.

Briefly, the Bayer process is as follows (see *Aluminium*, by G. Mortimer, 1919, pp. 22-23):—

The bauxite is crushed and ground to pass a 50 to 100 mesh screen. If the ore contains appreciable percentages of organic matter or combined water, it is previously calcined at a temperature not exceeding 400° C. The finely ground material, to which a little lime has been added in the grinding if appreciable percentages of silica are present, is then mixed with a measured quantity of caustic soda solution (specific gravity, 1·45) and well stirred. The mixture is then run into steam-jacketed autoclaves, also provided with stirrers. In these autoclaves the fluid is thoroughly digested, until, with the heat that has been applied by the steam, the pressure inside is raised to above 70 lb. per square inch. At this stage all the alumina is converted into soluble sodium aluminate, while the ferric oxide remains insoluble. The liquor from the autoclave is now blown out by its own pressure into large tanks, and there diluted (specific gravity, 1·23) with washings from previous filtrations. After further stirring in these tanks the liquid is passed through filter presses in which the insolubles, ferric oxide, etc., are removed, and the filtrate pumped into deep tanks. In these the clarified liquid is agitated by means of revolving paddles and loosely hung chains. A small quantity of hydrate of alumina is usually added to assist the precipitation of aluminium hydrate. When the precipitation is considered complete, the liquid is forced through further filter presses; in these the hydrate of alumina is obtained as a white granular powder. The filtrate containing the soda is thickened in special evaporators and used again. The hydrate of alumina is next calcined in a reverberatory furnace at a temperature of about 1000° C. to obtain the anhydride. The whole plant is elaborate and expensive. There are, as may be imagined, numerous precautions to be observed and adjustments to be made to prevent waste—either losses in insoluble alumina in the bauxite or of the caustic soda added in the working. However, with experience and care these losses are reduced to a minimum, and the working of the process is conducted efficiently. The correcting of the bauxite at first is very important, as upon this lies the saving of the relatively expensive caustic soda and its use over and over again. Among other items of importance must be mentioned the disposal of the ferric oxide (hydrate) slime which is collected at the filters. If there is a high percentage of ferric oxide in the bauxite, the amount of this slime will be large. It is generally run out as waste material, and entails handling and disposal, expenses which are not recoverable except in the selling price of the alumina. So far none of this slime has been used either as iron ore or as paint material—the slime could be utilised for both these purposes.

If the original bauxite was rich in titanium dioxide, this constituent would be removed with the ferric oxide (slime), and give an added potential value to the slime. The extraction of pure titanium dioxide from cheaply obtained titaniferous ores, ilmenite, etc., has become an important process in the manufacture of valuable white pigments—titanium white, titanox, etc. In this connection the following extract from *The Mining Journal* of 11 November, 1922, p. 841, is of interest:—

> "It has been known for several years that a white titanium pigment was being manufactured in America (BXX Titanox of the Titanium Pigment Co., Niagara Falls, N.Y.) and in Norway (the 'Kronos' titanium white of the Titan Co., A/S, of Fredriksstad). Particular attention has been directed to these titanium white pigments by the appearance of two papers—one titled 'Titanium White: Its Production, Properties, and Use,' by Messrs. W. H. Washburn and J. McGougan in the *Proceedings of the Paint and Varnish Society* (Session 1920-21, No. 3, pp. 41 to 61); and the other, an article on the same subject, by Mr. Noel Heaton in the *Journal of the Royal Society of Arts* (vol. lxx, No. 3631, for 23 June, 1922, pp. 552 to 556). There is little doubt that this new pigment has very valuable properties and an attractive future before it. It must, however, be made clear at this stage that the brands of 'titanium white' pigment on the market consist normally of about 25 per cent. of pure titanium dioxide mixed with 75 per cent. of barium sulphate (barytes). In some cases, owing to the extreme chemical inertness of the titanium dioxide in

the vehicle (usually linseed oil) it has been necessary to add considerable amounts of zinc oxide.

"It is claimed for titanium white pigment that it is of (1) dazzling whiteness; (2) it consists of particles of exceeding fineness; (3) it is light in weight; (4) of great permanence, owing to its inertness, either by exposure to acid fumes, fierce glare, or sea water; (5) it is non-poisonous; (6) weight for weight, it is said to have nearly three times the obscuring power (opacity) of white lead; and (7) owing to the above qualities it works well, spreads more evenly, and is more durable than any other white paint. The above remarks apply to 'titanium white' as distinct from pure titanium dioxide. The drawback has been the great cost of this pigment, the 'Standard' quality of the Titan Co. being recently quoted at £50 c.i.f. British port, packing included. The 'Extra' quality, containing more titanium dioxide, is quoted at £75 a ton.

"The raw materials from which the pure titanium dioxide is prepared are the minerals rutile and ilmenite. Large deposits of rutile are not common, whereas considerable deposits of ilmenite are known. For example, the beach iron-sands of certain parts of New Zealand are highly titaniferous, and the monazite sands of the Travancore coast in South India contain nearly 70 per cent. of ilmenite. The quantity of ilmenite in the latter deposits is estimated in hundreds of thousands of tons. It is in cases such as have been cited above, where by obtaining the ilmenite as a by-product in the recovery of another substance, that attention has been concentrated.

"The question of using the ilmenite in the monazite sands of Travancore has been very carefully considered by those interested in that branch of the Indian mineral industry. They have been faced with an exceedingly dull monazite market for the past eighteen months, and there is no immediate prospect of a trade revival in this mineral. This, it appears, is due to the fact that considerable stocks of monazite exist in Germany—enough, so it is reported, to supply thorium nitrate for the manufacture of gas mantles for the next two years. The cheapness of the German incandescent gas mantles is at present proverbial, consequently the monazite producers have been looking for some other means of maintaining their business. In these circumstances the manufacture of pure titanium dioxide has presented a solution. The process, as recently devised, is simple, and requires high-grade ilmenite in large quantities, cheap sulphuric acid and fuel to make it commercially profitable. The prepared substance has already attracted the attention of dealers and makers of paints and varnishes. A great deal of work has been done, and although it is too early to disclose the developments which are in progress, it is anticipated that a well-laid scheme, involving firms of good name and strongly-entrenched position, will presently emerge. It is estimated that with the existing price of materials, wages, and assembly costs the pure titanium dioxide, which is now being prepared in a semi-commercial manner, will be available at less than £30 a ton. This price is considerably below that of white lead or zinc white."

As stated previously, the hydrate of alumina obtained as a precipitate at the second filter presses are subsequently calcined. In this calcination process considerable quantities of alumina dust are carried away with the hot gases and steam into the flues of the reverberatory furnace. The heat in the distilled steam from the hydrate is used in feed water heating for boiler purposes, and some of the alumina is recovered as flue dust in special settlers known as Cyclones. However, much of this dust is contaminated with ash material, etc., from the coal used in calcining the hydrate, and can only be used as an abrasive or polishing material. There would appear to be room for considerable economy in this final calcination—in the process as at present conducted.

**The Deville-Pechiney** ("Carbonate" or "Dry Soda") process, although quite unsuitable for siliceous bauxites, proved very useful in its day for highly ferruginous bauxites. The crushed bauxite was thoroughly mixed with calcined sodium carbonate, and powdered coal, and the product calcined at a temperature high enough to cause chemical interaction of the constituents without producing fusion. The calcination at 1100° C. to 1400° C. is carried out in the cement type of rotary furnace. At the temperatures employed the sodium carbonate breaks up into soda and carbonic acid gas. The soda thus liberated combines with the alumina in the bauxite to form sodium aluminate. The sintered mass from the rotary furnace is dissolved in boiling water as soon as the evolution of carbonic acid gas has ceased. The sodium aluminate goes into solution in the water, while the insoluble components—ferric oxide, titania, silica as quartz or other insoluble form, etc.—are removed from their condition of suspension by filter presses, through which the liquid is passed. The solution is next agitated with warm flue gases containing carbon dioxide, and the unstable sodium aluminate breaks down and allows aluminium hydrate to precipitate :—

$$2Na_3AlO_3 + 3CO_2 + 3H_2O = 2Al(OH)_3 + 3Na_2CO_3.$$

**The Peniakoff Process** is similar to the Deville, except that sodium sulphate is used instead of sodium carbonate, *i.e.*,

$$2Al_2O_3 + 6Na_2SO_4 + 3C = 4Na_3AlO_3 + 3CO_2 + 6SO_2.$$

The sulphur dioxide is recovered as sulphate and hydrochloric acid. The sulphate being available for use again and again. Dry soda is obtained by both these processes.

**Griesheim-Elektron Process.**—After crushing and calcination the bauxite is boiled with sulphuric acid in excess. The aluminium content is precipitated from this liquor as aluminium sulphate, and the other impurities of the bauxite remain in solution.

The older, carbonate or dry soda process is still used when the character of the bauxite is appreciably ferruginous. The MacCullock process is also based on the old carbonate process, but is dependent upon the fact that the alumina is precipitated first and the silica afterwards ; consequently, by arresting the precipitation before it is completed, the bulk of the silica is left in the solution with a portion of the alumina and sodium carbonate.

**Serpek Process.**—There are various other processes, but perhaps the greatest interest is being taken in the Serpek process, because it utilises bauxite for the fixation of atmospheric nitrogen. The bauxite is calcined in an upper rotary kiln, and falls into a hopper, in which it is mixed with carbon, and then passed on to another kiln. In this it passes through an electric resistance furnace, which raises the temperature of the mixture to 1800° to 1900° C. At this stage it passes into an atmosphere of nitrogen and carbonic oxide, supplied from a gas producer. The conditions are suitable for the formation of aluminium nitride. The carbonic oxide passes upward, and is burnt in the upper kiln for the calcination of the raw bauxite. The process, besides opening up a source for the manufacture of ammonia, fertilisers and nitric acid, has as its main by-product a commercially pure alumina.

In all these processes the bauxite is first purified to aluminium hydroxide or to sodium aluminate, as in the Peniakoff process,

$$2Al_2O_3 + 6Na_2SO_4 + 3C = 4Na_3AlO_3 + 3CO_2 + 6SO_2,$$

or to aluminium sulphate, as in the Griesheim-Elektron process. The reduction to aluminium is effected electrolytically in an electric furnace.

Bauxite, however, is not the only source from which aluminium salts may be obtained for reduction to aluminium. In the Tone process, pure silica is obtained from kaolin and alumina is produced as a by-product. In the Peacock process, potash felspar is used, and silica and alkali are removed as alkaline silicates, while the alumina is left practically pure. A Norwegian company has invented a process for separating alumina from labradorite (soda felsspar), by means of nitric acid. There is little doubt that some economic method will be evolved by which alumina will be produced from clays more cheaply than from bauxite deposits situated at a considerable distance from a supply of cheap electric power.

The laterite occurrences in India, generally ferruginous in character, cover an enormous area, but the bauxite enrichments are an exceedingly small fraction of the total laterite. If efficient processes are used for the treatment of the Indian bauxite by firms which have long been known in connection with the extraction of aluminium, it is likely that these firms will thoroughly investigate the possibilities of the more ferruginous varieties of laterite, and possibly discover some process for utilising the vast quantities of laterite which cannot be used at present. Encouragement should be given to the development of a large bauxite works : preferably as recommended by Sir Thomas Holland, for the manufacture of alumina and various other salts. In process of time the various hydro-electric projects, which are now under investigation, may be completed, and, if the power is sufficiently cheap, it would not be a difficult matter to reduce the alumina to aluminium.

**Alumina Specifications and Contracts.**—At present upwards of

80 per cent. of the world's output of bauxite is used for the preparation of pure alumina. Although a small quantity of aluminium hydrate is utilised in the chemical industry, by far the larger percentage of pure alumina is calcined and marketed in the form of the anhydride. Practically all this calcined or burnt alumina is absorbed in the aluminium industry for the electrolytic separation of the virgin metal. The present prices average from £18 to £22 a ton for the hydrate, and £25 to £30 a ton for the anhydride, usually quoted f.o.r. vendor's works. It has been estimated that, allowing for working losses, the coefficient of transformation of bauxite into pure calcined alumina is about 2. Roughly, 2 tons of bauxite would therefore be required for the preparation of 1 ton of alumina. This applies to an average of all kinds of bauxite, *i.e.* to those of the French or Mediterranean, as well as to the Tertiary or Indian and American varieties.

In the majority of cases the manufacture of alumina from bauxite is carried out at works which are owned or controlled by one or other of the big aluminium companies. Consumers of alumina are consequently obliged to obtain their supplies at prices which are regulated by the various operating aluminium companies. During recent years there has been a considerable increase in the demand for aluminium, and certain branches of the metallurgical industry are beginning to find the monopolistic control in the production of aluminium rather irksome. The numerous occurrences of bauxite which have been lately discovered in various countries render it possible that new companies will come into existence for preparation of alumina and the production of aluminium. Existing alumina works naturally enjoy an advantageous position, owing to their being an integral part of large aluminium companies. Their supplies of raw material—bauxite, coal, caustic soda, etc.—are arranged for, and their output can be regulated by the demands of their related reduction works. An independent company would be faced with severe competition whilst establishing itself. However, there are several compensating factors, such as the recovery of rich titaniferous slime for pigment purposes from titaniferous bauxite. The chief impurities which are usually found in commercially pure alumina are sodium carbonate, moisture, silica, and ferric oxide.

The quality of the calcined alumina, which is at present considered suitable for the extraction of aluminium, appears to range between the following limits: Alumina, upwards of 97·5 per cent.; moisture, 0·5 to 2·0 per cent.; sodium carbonate, 0·5 to 1·25 per cent.; silica, 0·05 to 0·25 per cent.; and ferric oxide, 0·03 to 0·15 per cent. Although cases are known where consignments of alumina containing 0·6 per cent. total of silica and ferric oxide have been accepted at low prices, it appears that alumina consumers demand that the silica will not exceed 0·25 per cent., and the ferric oxide 0·15 per cent. with the right of refusal of the consignment if these agreed maximum percentages are exceeded. In the electrolytic separation of the aluminium from alumina, the silica and ferric oxide impurities in the latter would pass into the metal and thus contaminate it. In regard to the moisture and sodium carbonate, impurities which effect the economic working of the furnace, a penalty is levied, and the buyer obtains a credit on fractions of a per cent. above an agreed percentage, and has the right of refusal if the sodium carbonate and moisture exceed a definite amount in each case. The penalty on the vendor is roughly 5d. per tenth of 1 per cent. on every ton if the moisture exceeds 0·5 per cent., or the sodium carbonate exceeds 0·6 per cent., the permitted maximum in each case being 2·0 per cent., and 1·25 per cent. respectively.

The existing methods of determining the true percentage of the alumina content of a consignment leave much to be desired. This substance is usually found by difference, by determining the various impurities above enumerated and subtracting their total from 100. It is thus evident that a detailed analysis showing other impurities may give rise to disputes of quality. The vendor generally takes samples when the alumina is being bagged—say, a small amount from every tenth bag when each bag holds, roughly, 100 to 200 lb. The total sample is then halved, one lot is sent to the purchaser, and the remainder retained. The buyer satisfies himself as to quality, and then sanctions despatch of the waiting consignment and accepts delivery. Payment is made on a quality which is obtained by the buyer and vendor exchanging copies of their analyses on an agreed date. If the difference in the items of the two analyses do not exceed 0·20 per cent. for moisture, and 0·10 per cent. for all the other impurities together, an average is struck and the price calculated and put in the invoice. If greater differences appear in the analyses an umpire chemist is called in and his analysis accepted. The cost of this analysis is borne by the party whose results differ most from the umpire's analysis. The weight of a consignment on which payment is made includes an allowance of 1 per cent. for moisture. Above this amount the excess is deducted. The alumina is packed in sound bags, which are supplied by the vendor without an extra charge. As stated previously, the normal quotation is f.o.r. vendor's works, but there is an increasing desire on the part of certain purchasers, who have no other cargoes or no agents at the port of loading, to have the consignment quoted c.i.f. port of unloading. Payment is made net cash on presentation of the bill of lading at the time of despatch at the buyer's office, or that of his accredited agent.

Complicated transactions are sometimes contracted for which require very careful forethought. It may happen that a bauxite company will arrange with an alumina works for the purification of its bauxite, and then supply the purified alumina under guarantee of quality to an aluminium company. In such cases strict specifications of quality and stipulations regarding prompt delivery, both of the bauxite to the alumina works and the alumina to the aluminium company, are necessary. On the other hand, a somewhat liberal transformation coefficient of bauxite to alumina is allowed—2·5 tons of bauxite to the ton of alumina is permitted if the bauxite averages 60 per cent. $Al_2O_3$. No responsibility is, of course, accepted by either party in the event of breach of contract due to causes such as labour strikes, war, etc., over which they have no control.

## ALUMINIUM.

It is well known that almost all the aluminium of commerce is obtained in some simple form of electric furnace (the Hall-Hérault), using from 2000 to 20,000 amperes at a very low voltage (5 to 8 volts). It is a high temperature electrolytic process in which the electric current serves not only to maintain the bath in a molten condition, but also for the deposition of the molten aluminium at the cathode. Alumina is dissolved in molten cryolite. When a low voltage current is passed through this solution the alumina is disintegrated into its components, oxygen and aluminium, the metal sinks to the cathode, and the liberated gas burns to carbon dioxide at the carbon electrodes of the anode. The cryolite should, theoretically, remain unaffected, and on paper the whole process appears wonderfully simple. In practice, there are many pitfalls, and an enormous amount of care is necessary in the control and working of the plant (see *Aluminium*, by G. Mortimer, 1919, pp. 29 to 40). The furnaces can be worked at a temperature of 915° C. with about 5 per cent. of alumina in solution. The melting-point of cryolite is, roughly, 1000° C., and the melting-point of a solution with 20 per cent. alumina is about 1015° C., so that an excess or diminution of alumina tends to diminish the economy of working. In normal working, between 6 to 7 volts, the cryolite is also gradually decomposed, and fresh material has to be added from time to time. The consumption of the carbon electrodes constitutes a large part of the cost of production, as they are made from the purest form of carbon, *i.e.* petroleum coke with tar as a binding material. There is also the ever-present danger that the molten aluminium may float to the surface of the bath, short circuit the furnace and, catching fire, burn back to alumina. This possibility arises from the closeness of the specific gravity of the substances used, as seen below :—

| | Solid. | Liquid. |
|---|---|---|
| Commercial aluminium | 2·66 | 2·54 |
| Greenland cryolite | 2·92 | 2·08 |
| ,, ,, (Saturated with alumina) | 2·90 | 2·35 |

The margin in such a furnace evolving gas is obviously exceedingly small. It is customary, however, to add a flux, usually aluminium fluoride, which decreases the specific gravity of the solution, lowers the melting-point to about 800° C., and allows the bath to dissolve 10 per cent. more alumina. The average yield of metal is 1 lb. for every 2 lb. of alumina. The consumption of the carbon electrodes at about £15 a ton is from 1 to 3 lb. per lb. of metal obtained. The losses in cryolite and flux average $\frac{1}{4}$ lb. per lb. of aluminium produced.

PHOTOGRAPH XII.

[*Per favour: British Aluminium Co., Ltd.*

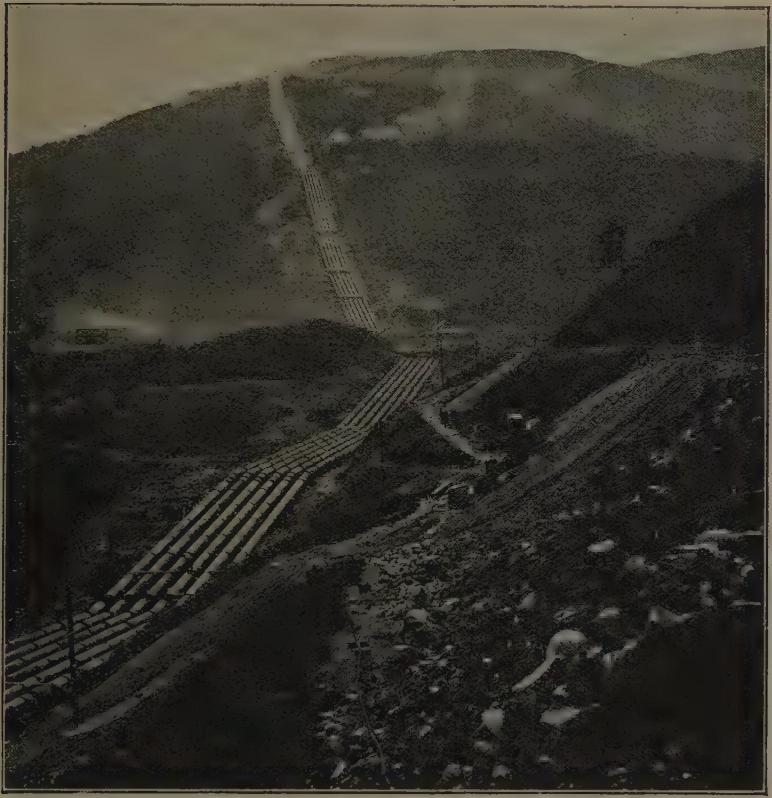
Aluminium Reduction Works and Pipe Line, Kinlochleven, Argyllshire, Scotland.

The following extract from "The Electric Furnace in Metallurgical Work," *U.S. Bureau of Mines, Bull.* 77, 1916 (pp. 75-77), regarding the Hérault process for the manufacture of Aluminium, is also of interest :—

> In principle, the Hérault process is the same as the Hall process, the reported differences being in the composition of the electrolyte, and possibly in the shape of the furnace. In fact, the two processes are so similar that when the discovery of the reaction was made simultaneously, there was no patent litigation, but the Hall Company took the American field and the Hérault people the European, a condition that was maintained until recently, when the last of the Hall and allied patents expired in the United States. Now the Hérault interests are erecting a plant in North Carolina.

In Europe, at the present time, the manufacture of aluminium is conducted exclusively in furnaces (see Fig. 37) having a carbon block as the cathode, forming the bottom of the furnace, upon which the molten aluminium collects, and several upper carbon anodes, while the bath is kept molten entirely by the heat generated due to the passage of the electric current. The cross section is in all cases rectangular. The furnaces seen recently by one of the writers at a French aluminium plant were rectangular, and of the general shape of the Hérault steel furnace, but not so large. They were about 5 feet long, 3 feet wide, and 3 feet deep externally. Each furnace rested on the floor of the building without special foundations, so that furnaces could be picked up and moved around readily with a crane. There were eight carbon anodes projecting into the bath and connected to the positive side of the circuit, while the electrodes in the carbon bottom are connected to the negative side of the circuit. There is an electrode in the bottom corresponding to each of the anodes. In this case the bottom is only partially covered by the molten aluminium.

PHOTOGRAPH XIII.



[*Per favour: British Aluminium Co., Ltd.*

Another view of Pipe Line to Hydro-Electric Power Station, Kinlochleven.

A second type of furnace has a bottom composed of a mixture of tar and ground coke or electrode waste, which is rammed in around four large iron plates connected to the negative side of the circuit. There are four rows of anodes containing six to eight electrodes per row. In both types of furnace the bottom is inclined toward the tap hole, and each electrode is arranged so that it can be regulated independently of the others.

In the Hérault as in the Hall process the composition of the bath is kept secret, but in both processes the specific gravity of the bath must be less than that of the metal, so that the latter can collect on the bottom. Cryolite melts at 1000° C., but its melting-point is reduced to 915° C. by the addition of 5 per cent. alumina. By the use of calcium fluoride the melting-point of cryolite can be further reduced to 800° C. Cryolite has a specific gravity of 2·92 when solid and 2·08 when liquid, whereas aluminium has a specific gravity of 2·6 when solid and 2·54 when liquid. It is not considered advisable to have more than 25 per cent. of aluminium, in the form of alumina, in the molten bath. Although aluminium fluoride can also be used for lowering the melting-point, the most common flux is calcium fluoride.

Theoretically, 42 grams (0·092 pound) of aluminium per kilo-watt-hour should be produced by the electrolysis of alumina in a bath of cryolite. Practically, the foreign manufacturers using the Hérault process make 30 grams (0·066 pound) of aluminium per kilowatt-hour, which gives an efficiency of 71 per cent.

The furnaces take about 75 kilowatts each and produce from 50 kilograms (110 pounds) to 55 kilograms (121 pounds) per twenty-four hours. The voltage used is from 8 to 10 volts and the density of current from 1·5 to 3 amperes per square centimeter. The consumption of alumina per pound of finished aluminium is theoretically 1·888 pounds and practically 2 pounds. For each pound of aluminium produced there is a consumption of 0·1 pound of cryolite and 0·9 pound of carbon anodes.

The main progress in aluminium manufacture, as far as can be determined, has been in the purification of the bauxite into alumina before it is charged into the electrolytic cell, mention of which has already been made.

**Uses of Aluminium.**—In pamphlets issued recently, the British Aluminium Company, Limited, give a very frank statement of the advantages and limitations of the use of the metal. The soldering of aluminium has always been difficult and unreliable, but by actual welding the metal can be made into vessels of any shape and size. Aluminium, though suitable for many purposes, is unable to resist corrosion from hydrochloric acid, halogen solutions, or caustic alkalies. The metal is slowly attacked by nitric and sulphuric acids, but is better than most other metals in resisting chemical corrosion. It is possible to store oleic, stearic, and palmitic acids in aluminium tanks.

The metal is replacing woodwork to a large extent in the building of railway carriages, motor cars, storage receptacles for liquids, and various other purposes. The replacement of copper conductors on electrical transmission lines is frequently an economic advantage. Aluminium is also very largely employed in the aircraft industry for engines and stays, wires, and even wings of aeroplanes.

There is an enormous demand for aluminium alloys.

"At a meeting of the Foundry Congress held recently at Nancy, M. de Fleury gave an address on the new aluminium alloy which has been named Alpax, after the name of its inventor, Dr. Alendar Pacz. M. de Fleury described the new product as *an aluminium-silicon alloy, containing* 13 *per cent. Si.* A wide range of applications is anticipated for it, as it is believed to supply a real need—viz., a light foundry alloy which possesses high tensile strength, and which is not brittle.

PHOTOGRAPH XIV.

[*Per favour: British Aluminium Co., Ltd.*

Steel-Cored Aluminium Cable, Spans of 1100 feet, crossing Yodo River, Japan,

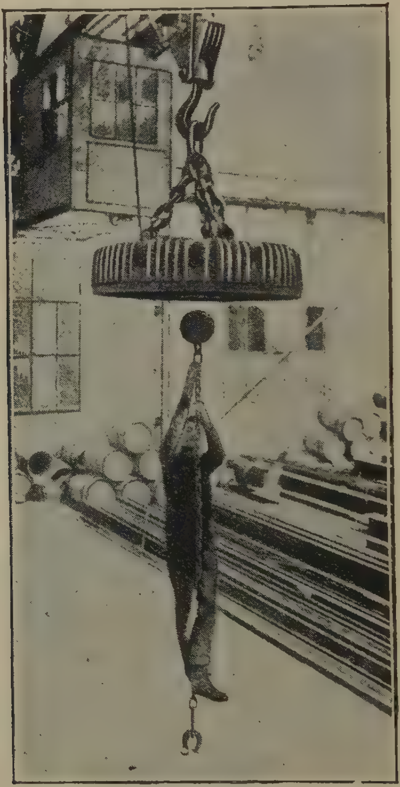
PHOTOGRAPH XV.

[*Per favour: British Aluminium Co., Ltd.*

Aluminium Busbars in one of the London G.P.O.'s sub-stations.

It is understood to be obtained by a special crucible treatment consisting, roughly, in the superheating of aluminium in the neighbourhood of 900° C. in the presence of alkaline salts, the composition of which is a secret. The bath is skimmed at about 800° C. and the contents run off at the usual temperature. The density is given as 2·64, or 10 per cent. under the density of the usual foundry aluminium and one-third that of steel. Among the advantages claimed for the alloy are its exceptional mechanical strength, which at 300° C. is stated to be higher than that of any other foundry aluminium alloy, its non-brittleness during the solidification period, and its suitability as a frictional metal. As regards corrosion, it is stated that the experiments show atmospheric conditions to be of little importance, the alloy being unaffected by moist air and considerably less affected by dilute nitric acid than pure aluminium. It is considered to be particularly suitable for automobile construction, and a large and varied range of Alpax castings were on view at the recent Salon de l'Automobile. The lecturer said that the applications already found for the material in this connection suggested that in the course of the next three or four years the tonnage of aluminium at present employed in the industry could, for the same number of vehicles, be trebled. In Germany, where the alloy has been given a different name—that of Silumin—it has been used in railway construction as a substitute for bronze." (*The Mining Journal*, 11 November, 1922, p. 841.)

PHOTOGRAPH XVI.



[*Per favour: British Aluminium Co., Ltd.*

Electric Lifting Magnet embodying Aluminium (Wire) Windings.

**Thermit Welding.**—The Thermit process of welding depends on the powerful affinity which aluminium possesses for oxygen, and owing to which it is difficult to solder aluminium. However, if a mixture of finely granulated aluminium and iron oxide is ignited by a strip of magnesium ribbon, the combustion so started attains a temperature of nearly 3000° C., and the whole mass becomes molten. This property is the principle which has been developed by Professor H. Goldschmidt into the so-called Thermit process. The welding of iron and steel is effected by this means, for the molten mass of thermit separates into two layers, an upper layer, two-thirds of the whole volume, being aluminium oxide (alumina), as artificial corundum, and a lower layer of pure molten iron. It is possible to obtain pure metals, other than iron, by using their oxides with powdered aluminium, as was done in the case of ferric oxide. By this means chromium, manganese, molybdenum, and cobalt may be obtained of sufficient purity for use with steel for the production of high-speed tool steel, manganese steel, special tool steels, and stainless cutlery.

**Explosives : Ammonal.**—This enormous liberation of heat caused by the combination of finely divided aluminium and oxygen has been utilised for the production of the high explosive, ammonal. It is a safe explosive, consisting of a mixture of aluminium and ammonium nitrate, which can be fired with a suitable detonator, resulting in a violent smokeless explosion with the production of nitrogen, steam, and alumina as the products of the explosion. It has a shattering, disruptive effect, best utilised in bombs.

**Aluminium Paints.**—The Aluminium Company of America have issued a special handbook on "Aluminium Paint." They recommend the use of powdered aluminium bronze with the particles in fine, polished, flake form. The flake form allows of "leafing" when the paint is steadily smoothed down with a brush. The powder is mixed with heavy-bodied linseed oil with a drier incorporated. It may be applied to the cleaned surface either by means of a brush or by spraying. The following extract from this handbook sums up the uses of aluminium paint :—

> Aluminium paint can be used wherever a protective coating is desired on metal, wood, or concrete. Its remarkable waterproofing power enables it to protect steel from rusting by keeping out moisture. Used as a priming coat on wood, the same ability to resist moisture keeps the wood from swelling and cracking. In addition to its universal applicability as a protective paint, its other special properties give it special uses. For interior painting its brightness assists in obtaining high lighting efficiency. Its high reflectivity also adapts it for use on oil storage tanks and other structures which it is desired to protect from the heating effect of sunshine. Its high reflectivity is easily maintained, since dirt adheres to it less readily than to other paints. It may also be easily washed.
>
> The non-transparent flakes of aluminium give aluminium paint unusual hiding power and make it useful wherever it is desired to hide a surface as, for example, in

converting dark-coloured surfaces to light ones. This unusual hiding power makes it necessary to use only one coat on much interior work. On furnaces and other heated surfaces it reduces radiation, and thus saves heat and promotes the comfort of workers. The user will find it comes in handy for almost every purpose for which paint is used, and where the aluminium colour, high protective, hiding, and waterproofing properties are desirable.

The application of aluminium paint is thus referred to in *The Mineral Industry* during 1922, page 22, 1923 :—

*Calorizing.*—Calorized parts are being employed to a considerable extent for high-temperature work, and a good discussion of calorizing is given in an article by Howe and Brophy.[1] As is known, the colorizing process consists in the formation of a surface-coating of aluminium on ferrous and non-ferrous metals and alloys, and there are now two commercial methods for calorizing, viz., (1) The powder process, and (2) the dip process. The latter process has been developed by C. Dantsigen of the General Electric Company. Calorized pipe for oil refining is being employed to a considerable extent, and calorizing is finding many new applications. A large new use is for stove parts, such as burners for oil and gas stoves. Metal parts coated with aluminium by spraying (*i.e.* with the Schoop pistol) are being employed somewhat. In Germany and France grate-bars for locomotives are sprayed with aluminium, and such bars have been found to give much better service than bare bars. Iron containers for chemical plant and centrifugals for use in the preparation of gun-cotton are sprayed with aluminium. Guillet [2] has discussed the protection of parts by coating with aluminium ; in France the protection is known as " aluminage."

**Aluminium Refining.**—The following extract from an editorial in *The Mining Magazine* for July, 1925, is of very considerable interest :

In the various discussions relative to the possible or probable exhaustion of the world's resources of metals and metallic ores it has been generally alleged that aluminium, though widely distributed in nature, will never become an effective substitute for copper and other non-ferrous metals, because its ore, bauxite in a sufficiently pure form, is of limited occurrence, and that any hopes of a supply of the metal from other aluminous materials will end in disillusionment owing to unsurmountable chemical and metallurgical difficulties. We have ourselves attempted to combat this gloomy view as to the future of aluminium, believing that there is no inherent reason why the extensive investigations of those engaged in this branch of metallurgy should not eventually yield favourable results. In this connection it is of interest to call attention to recent work done by the metallurgists of the Aluminium Company of America, some details of which were published in a paper by Mr. F. C. Frary, quoted elsewhere in this issue.

The new invention consists of a method of refining impure aluminium and thus producing ultimately a high-class metal from low-grade or complex ores not hitherto applicable in the metallurgy of aluminium. Briefly, an electrolytic bath has been discovered in which the impure anode remains at the bottom of the cell, with the electrolyte floating upon it, and the refined metal, or cathode, floating on that, the question being chiefly one of relative specific gravities. Another point in the invention is that the electrolyte is constituted in such a way as to encourage the formation of a non-conducting crust on the sides of the cell, so that short-circuiting of the current is avoided. It is not necessary here to recapitulate the details of the methods for securing these results, as they are given in Mr. Frary's account, but it may be said that an important point is the addition of copper to the impure aluminium in order to make an alloy sufficiently heavy to remain always at the bottom, and another is that iron and titanium must be mostly removed, as they tend to raise the melting-point of the anode.

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[1] G. H. Howe and G. R. Brophy, " Calorising and Calite," *Gen. Elec. Rev.*, **25**, 267-272 (1922).

[2] L. Guillet, " Les Recouvrements par l'Aluminium," *Rev. de Mét.*, **19**, 296-297 (1922).

The commercial results of the discovery are of considerable importance. In the first place, it will no longer be necessary to produce a pure alumina before treatment of the aluminous material in the electric reducing furnace, an expensive preliminary chemical process being thus eliminated. On the other hand, aluminous minerals of all sorts and of various degrees of purity will become amenable, such as any form of bauxite comparatively high in iron and titanium, and even ordinary common clay. In the first smelting operation on this raw material there would be obtained, in addition to the impure aluminium afterwards to be refined, most of the iron and silicon in the ores, and these would combine to form ferro-silicon, a product always saleable.

If the new process succeeds in practice (and there is no reason to suppose that the inventors have published prematurely), it would appear that the technical difficulties of producing pure aluminium from low-grade material have been overcome. The question of relative cost is one which will require consideration, for owing to the large amount of current required in smelting, and also to the low grade of much of the material now made amenable, the process will still be comparatively expensive. On the other hand, the raw material will be much cheaper, and the preliminary chemical treatment will be entirely avoided. A favourable feature of some importance is that the smelting and refining processes will be continuous, that is to say, the metal will not undergo any cooling and re-heating between reduction and refining. Also, some of the by-products will bring an income, as already mentioned. It conclusion, we may say that it is greatly to be regretted that the chief inventor, Mr. William Hoopes, has not lived to enjoy the fruits of his labours: all the more reason why his name should be suitably perpetuated in the roll of fame.

The obvious comment to be made with regard to the above process is that it is difficult to see how the floating molten metal will be prevented from oxidising and catching fire.

## Chemical Uses

The raw material bauxite is invariably purified or combined into one or other of the various aluminium salts, which are directly used in the various chemical industries of dyeing, printing, tanning, water purification, and treatment of sewage. In these cases the effects required are produced by a peculiar behaviour of the salts of aluminium. For example, the oxidisable impurities in sewage are negative colloids in the form of sols, and can therefore be precipitated by positive sols, such as the aluminium hydroxide sol, or by aluminium salts (in this case the precipitation is not caused by the hydrolysis of these salts into the above positive sols, but by the powerful precipitating effect of the trivalent cation, $Al'''$ on negative sols).

G. D. Hubbard ("Colloids in Geologic Problems," *Amer. Jour. of Science*, vol. iv., 1922, p. 101) says of coagulation or flocculation of sediments :—

> It has long been known that even the finest sediments which come out to the sea in the waters of our great rivers fall to the bottom long before they get far into the sea, and that the main body of the ocean is made comparatively clear water. This speedy precipitation of sediments has also been ascribed to the saltiness of the sea, but the connection had not been worked out until recent studies in colloids and their relations to electrolytes.
>
> An electrolyte is a salt, or in some cases a base or an acid, in water solution through which electric current flows. Salts are generally better electrolytes than acids. The theory is that the electrolyte is ionized, e.g., sodium chloride becomes $Na^+$ and $Cl^-$ in solution, magnesium chloride becomes $Mg^{++}$ and $2Cl^-$ in solution. The higher the valence of the base part of the salt (the positive ion) the more powerful the electrolyte as a coagulant of negatively charged suspensions, and the power seems to bear no definite relation to the valence. Aluminium chloride, for example, is hundreds of times more potent than sodium chloride. The charge on the electrolyte and on the colloid must be of opposite sign. The aluminium ion of $Al_2(SO_4)_3$ has a positive charge, and aluminium is trivalent in the sulphate. Since most colloids are negative, aluminium sulphate is one of the most effective flocculators.

**Aluminium hydroxide** possesses a powerful affinity for many organic substances, and enters into association with a large number of colouring matters, precipitating them completely as *lakes*. On this property depends the use of alum mordants. They precipitate the hydroxide upon the fibre of the goods to be dyed, and this constitutes the fixing agent, or *mordant*, which retains the colour.

**Sodium aluminate** is now prepared on a large scale for use as a mordant, or as an intermediate product in the preparation of the sulphate and other salts of aluminium. The concentrated solution rapidly deposits alumina, leaving in solution a basic aluminate. The alumina obtained from this salt is pure and free from alkali, and can be used as a mordant in calico printing and dyeing in an acid, but not, as in the case of alum, an alkaline bath. For the production of *lakes* the colouring matter is mixed with the aluminate solution and precipitated by the addition of sulphuric acid.

**Aluminium chloride** is obtained by dissolving the hydroxide in hydrochloric acid. It has been recommended for the preservation of wood. An impure chloride containing calcium and sodium salts appears to be used as a disinfectant under the name "chloralum." The following occurs in *The Mining Journal*, 19 May, 1923 :—

### ALUMINIUM CHLORIDE AND ITS IMPORTANCE TO THE OIL INDUSTRY.

> *Washington*, D.C., May 6th.—Development of cheaper processes for the production of anhydrous aluminium chloride, a chemical used in the refining of petroleum, should lead to an enormously increased consumption of this material in the United States, according to the Department of the Interior, which has made a study of the matter at the Pacific experiment station of the Bureau of Mines, Berkeley, California.

Expansion in the output of anhydrous aluminium chloride would, in turn, tremendously increase the production of chlorine and aluminium, the raw materials used in its manufacture. In fact, the reduction of the cost of aluminium chloride to a point where its use could become general with petroleum refiners probably necessitates the production of chlorine and aluminium in much greater quantity than the present capacities of these industries would admit.

Anhydrous aluminium chloride is a pure white micro-crystalline solid, which is usually yellow to brown, or bluish to greenish, due to the presence of impurities, especially iron. The technical advantages of anhydrous aluminium chloride in petroleum refining are so great that cost alone deters its greater use, states Oliver C. Ralston, assistant chief metallurgist of the U.S. Bureau of Mines. It is used to convert all unsaturated compounds into saturated compounds, resulting in the conversion of unstable gasoline and lubricating oils made from asphalt-base petroleum into excellent staple products of good colour and odour practically equal to paraffin-base products. Another effect obtained by boiling pertoleum products in the presence of aluminium chloride is a cracking action, by which high-boiling hydrocarbons can be converted into low-boiling hydrocarbons, with the formation of some coke and some fixed gases as by-products. A top oil, a gas oil, or a fuel oil can be treated to obtain a yield of 60 to 85 per cent. of low-boiling oil containing fractions of petroleum ether, gasoline, and kerosene, with a residue of coke, or the distillation can be stopped at an earlier point and excellent lubricants obtained in the heavier fractions remaining. A third function of aluminium chloride in petroleum refining is to remove sulphur from the oil.

Oil men, Mr. Ralston states, seem to agree that, if a cheap aluminium chloride is made available, nearly all the oil-refining companies will come to use it. If this were to happen, a supply of raw materials for making aluminium chloride would need to be assured. Assuming that 200,000,000 barrels of oil are refined per annum, and that an average consumption of aluminium chloride is 10 lbs. per barrel, the annual consumption of aluminium chloride would be 1,000,000 tons, necessitating 800,000 tons of chlorine and 200,000 tons of aluminium. The present chlorine consumption of the United States is probably not over 100,000 tons per annum, and bauxite for the production of 200,000 tons of aluminium is not available. The conclusions are that additional plants for producing chlorine would have to be built, and an outlet found for the caustic soda or caustic potash, which is simultaneously produced; and that aluminium chloride should be made from some raw material other than bauxite—probably clays, feldspars, or other silicates of aluminium. If only one-fourth of the country's crude oil production were refined by the aluminium chloride process, it can be seen that both the chlorine and the aluminium producing industries could be seriously unbalanced unless they were prepared to cope with new conditions.

Based on this consideration, any of the proposed production processes must be considered of little value unless they can eventually produce aluminium chloride for about 10 cents a lb. at most; moreover, the supplies of raw material should be adequate.

The first large scale use of aluminium chloride was in the preparation of aluminium metal by the reaction of sodium metal on the fused double aluminium-sodium chloride.

Anhydrous aluminium chloride is also used on a large scale as a catalyser in the manufacture of many dyes, perfumes, drugs, and pharmaceuticals.

Aluminium chloride is also being considered for the bleaching of brick, as red brick can be bleached to buff if iron is replaced by aluminium. Some steel companies have claimed, moreover, that the chloride could be used in removing certain impurities from molten metal. Any of the uses mentioned might develop on a larger scale if a cheap product could be produced.

**Aluminium sulphate** is produced by dissolving either bauxite or china clay in sulphuric acid. Bauxite is more readily soluble and needs no preliminary calcination. The chief drawback is the presence of large percentages of iron. When the solution is evaporated and cooled the salt solidifies as a greenish-yellow cake, which is sold as alumino-ferric cake under the names "concentrated alum" and "alferite" (see Thorpes' *Dictionary of Applied Chemistry*, vol. i, 1921, p. 172). The commercial aluminium sulphate contains appreciable quantities of iron. The article can be used in the preparation of all but the finest papers, in the precipitation of sewage, and the clarification and decolorisation of water supplies. Pure aluminium sulphate is prepared directly from pure alumina. In the preparation of this salt it has been found that

> "if French bauxite be used alone great difficulty is experienced in the clarification of the liquor; with a mixture of Irish and French bauxites, however, rapid settling occurs, and a perfectly clear liquid is readily obtained. It is of importance also, in this connection, that the liquor should retain a small amount of free acid, as the fully neutralised solution settles very slowly." (Thorpes' *Dict. of Appl. Chem.*, vol. i, 1921, p. 172.)

**Alum.**—At the present time the bulk of the alum manufactured in England is prepared either from shale or alunite, or from the aluminium sulphate derived from bauxite or china clay. It is extensively used in various industries: dyeing, printing, for shower-proofing fabrics, in the manufacture of lake pigments, the dressing of leather, the sizing of paper, and in the production of fireproofing materials. In most of its applications, however, it is being replaced by aluminium sulphate, which is considerably more economical (see Thorpes' *Dictionary of Applied Chemistry*, vol. i, 1921, pp. 171-172).

**Purification of Contaminated Liquids.**—It has been already stated that aluminium hydroxide absorbs certain organic compounds. The use of clays as clarifying agents has proved particularly successful in the treatment of slightly oily effluents of spinning works, wool-scouring plants, distilleries, tanneries, dye-works, glue-works, breweries, and other industries producing waste liquids contaminated with organic matter in a finely divided or colloidal state. The organic matter of the fluid carries a positive charge, and is therefore precipitated by colloidal matter carrying a negative charge. Domestic sewage, on the other hand, carries a negative charge, and is precipitated by aluminous colloids. The lithomarge which underlies the primary laterites may be a possible material for use in precipitating the oily substances in the liquids discharged from such chemical works as are enumerated above, but bauxite may not be so employed. The colouring matter in many swamps is generally positively charged, and therefore requires the clayey substance and *not* powdered bauxite for the clarification of the water. Humus, on the other hand, is a negative colloid, and can therefore be precipitated by positively charged colloids, such as aluminium hydroxide and ferric hydroxide.

## ABRASIVES.

**Bauxite for Abrasive Purposes.**—A substance which possesses the hardness of natural crystalline corundum could easily be marketed if it were possible to produce it cheaply and utilise it for the manufacture of grinding wheels, rubbing bricks, hone stones, polishing powders, etc. The best grades of natural pure corundum average from 95 to 99 per cent. alumina, with small percentages of silica and ferric oxide as impurities. A lower grade of corundum, consisting of a finely intergrown mixture of corundum and magnetite crystals, is the substance known as "natural emery." Large occurrences of corundum and emery are not common, and in consequence of the increasing demand for such material for abrasive purposes, an important industry for the manufacture of artificial corundum and emery has developed. In the majority of these new works the raw material used is calcined bauxite. This ore is fused in an electric furnace of the arc type, and the melt allowed to cool sufficiently slowly to become crystalline when solid. The solid "pig" is then removed from the furnace, broken up and crushed, mixed with a suitable binder, and made into the various types of grinders' tools, wheels, bricks, etc., required, and these raw manufactured articles are burnt or baked in kilns before being ready for the market.

There are several artificially prepared types of corundum and emery goods now available which have been made from bauxite in the general manner described above. It is obvious that the quality of the abrasive will depend on the quality of the bauxite used in its preparation. High-grade bauxite with little or no silica or ferric oxide would give very high-grade corundum, whereas a ferruginous bauxite would invariably produce emery. On the market these artificially prepared corundum and emery goods bear the trade name of the manufacturers. "Aloxite," which contains upwards of 94 per cent. alumina, is made by the Carborundum Company. They have works at Niagara Falls and, to be near the French bauxite, at Sarancolin in the Hautes Pyrenees. "Alundum" is a very similar material, and is prepared by the Norton Company of Chippawa, in Canada, and sold by them in two grades, "white" and "ordinary." "Boro-carbone" is practically only another quality of aloxite, and is also manufactured by the Carborundum Company in France and at the Niagara Falls, but its sale is controlled by the Abrasive Company of Philadelphia, Pa. (see F. B. Jacobs, *Abrasives and Abrasive Wheets*, 1919, pp. 53-62).

Two classes of abrasive materials rich in alumina are evidently available, those made by mixing calcined bauxite with binding materials such as lime, sodium silicate, fire-clay, etc., and sold as bauxite brick, and those produced by the electric fusion of bauxite. These constitute the so-called beta-alumina type (the alpha-alumina being natural corundum). The various trade names under which these artificial abrasives are sold are, among others, alundum, aloxite, exolon, lionite, etc. They are made into powders, bricks, grindstones, and emery wheels. All these stand very high temperatures.

**Building Stones.**—Large quantities of laterite are used for building purposes in those areas where no other more suitable material is available. The rock is soft and easily quarried. It has been used in great blocks for the breakwater at Marmagoa harbour. In some laterite areas, the slow-setting and hardening properties of the material have been thought to qualify it for use as road metal, with the result that under heavy traffic roads made with it are thick with red dust. Bauxite (lateritic) would be far superior to ferruginous laterite for building or road purposes. In the latter type of work it is evident that the wear of the surface should be taken by a harder substance. It is to be remembered that limestone, laid with tar, and covered by a thin carpet of asphalt sprinkled with coarse sand (to " take " the wear), is now frequently used as road metal. Bauxite would do quite as well if no other road metal was available. For building purposes generally bauxite is eminently suitable for facing walls which are exposed to acid atmospheres, etc. The substance alumina is exceedingly durable and insoluble.

## Cement Making.

**Bauxite Cements.**—Some years ago patents were taken out for using bauxite in the preparation of certain plaster compositions. The bauxite was incorporated as hydraulic calcium aluminate to give a quick set to the plaster ; 86 per cent. dry hydrated lime, 10 per cent. calcium aluminate (40 per cent. $Al_2O_3$), 2 per cent. plaster of Paris, and 2 per cent. infusorial earth are thoroughly mixed and ground together (see "Mineral Resources," *U.S. Geol. Surv.*, 1911, part 1, p. 931). Broadly speaking, cements which contain larger percentages of alumina and smaller quantities of lime set more quickly than others. It is therefore possible that bauxite could be utilised with an impure, siliceous limestone, and there is no secrecy about the process. At one cement works in India the aluminous clay which was being used was a siliceous variety of the lithomarge which occurs under cappings of primary laterite. To neutralise the effect of this the chemist in charge of the works temporarily used bauxite until a better quality clay was obtained, when the extravagant use of rich bauxite was discontinued. The cement of that factory was so quick-setting, as a result of the use of bauxite, that powdered barytes in small percentages had to be added to retard its setting. The occurrence of limestone and bauxite in juxtaposition in France, Dalmatia, and elsewhere has led to an experimental manufacture of an aluminate cement (*ciment fondu*) which is said to set very hard, possess remarkable strength, and be unaffected by sea water. The results have been so satisfactory that the following remarks may prove of interest.

It has been known for several years that Portland cement deteriorates rapidly when exposed to waters containing sulphates; the failure is said to be due to the formation of sulpho-aluminate of lime. This substance combines with water and undergoes crystallisation with a large increase in volume. Experiments by the United States Bureau of Standards, and other investigators, particularly M. Bied, in France, led to the preparation of high alumina cements. These cements are essentially calcium aluminates low in silica. They have been manufactured by fusing together bauxite, coke, and limestone, with occasionally slag or schist of suitable composition, in a small blast (cupola) or electric furnace, the fused product being then poured, cooled, and ground to make the finished product (see *Engineering* for 11 Aug., 1922, p. 180). The prepared product has an approximate composition of 40 per cent. alumina, 35 to 50 per cent. lime, 8 to 12 per cent. silica, and from 2 to 14 per cent. ferric oxide. No special quality of bauxite appears to be necessary, though the resulting cements are not equally efficient. The manufactured high alumina cements are sold as "fused cements," "Lafarge cement," "*ciment électrique*," "*ciment fondu*," etc. *Ciment fondu* is being manufactured by the Société Anonyme des Chaux et Ciments de Lefarge et du Tiel, who have works at Tiel and Montiers (Savoie). *Ciment électrique* is reported to be available from the Bureau d'Organisation Economique, and it is manufactured by the Société des Produits Chimiques d'Alais, Forges et Camargue, at their Argentière works. Quite recently the Lafarge Aluminous Cement Company, Ltd., have established works in England and opened an office at Lincoln House, 296-302 High Holborn, London, W.C. 1.

A considerable amount of attention was given to these cements during the Great War. High alumina cements, because of their quick-setting properties and fast development of their full strength, were used in the construction of heavy gun emplacements, "pill-boxes," etc. However, for various reasons now known, these high alumina cements did not fulfil the results then expected of them. They set too quickly, and were rapidly affected to their disadvantage if contaminated with lime or Portland cement before or during use.

Since the war they have been used with these precautions, and have proved of great value in difficult cases. Some of these uses have been: Concrete piles, masonry exposed to sea water, caissons, tunnels through strata contaminated with sulphates, etc. The advantages this material possesses over Portland cement are its immunity from deterioration when exposed to sea water, waters or soils containing sulphate salts, its rapidity in setting and attaining full strength. It is stated that in typical tests the tensile and comprehensive strengths obtained by high alumina cements in a few hours were greater than those of Portland cement after several weeks. The following figures (quoted from *Engineering* of 11 Aug., 1922, p. 180) are of interest: *Ciment fondu*, tensile strength 59 kilograms after 48 hours and 71 kilograms after 28 days, as against 55 kilograms in 28 days for Portland cement. The compression results were 687 kilograms per square centimetre in 48 hours and 959 kilograms in 28 days for *ciment fondu*, as against 612 kilograms in 28 days for Portland cement.

The value of these physical properties will be at once evident to the civil engineer, and although the present cost of the material is nearly double that of Portland cement, must appeal to him as being the most suitable substance in every way for particular purposes; the high cost is largely due to the expense involved in fusing the raw materials. It is claimed that careful calcination is sufficient, but so far the best results have been obtained by fusing the raw material. The commercial preparation of this type of cement is still in its infancy, and much is expected from the investigation now in progress.

## PETROLEUM REFINING.

**Bauxite for Petroleum Purification.**—It has been known for many years that Fuller's earth is capable of exercising a selective action on petroleum by retaining the unsaturated hydrocarbon and sulphur compounds which are in the oil. This remarkable property was utilised in oil refineries in the United States and other countries, and the theoretical aspects of the phenomenon has been ably discussed in numerous papers (see *Proc. Amer. Philo. Soc.*, 36, No. 154, 1897; Bulletin 315, *U.S. Geol. Surv.*, 1907; Richardson and Wallace in *Journ. Soc. Chem. Ind.* for March, 1912; and numerous other papers). Investigation has shown that colloids such as alumina, bauxite, Fuller's earth, etc., when freshly ignited (about 500° C.), acquire the curious property of actively attaching to themselves (on their surfaces), by absorption, other colloids and certain reactive substances, colouring matter and sulphur compounds in particular being readily absorbed when kerosene is filtered through freshly treated bauxite.

This decolorisation and desulphurisation of mineral oil by Fuller's earth, bauxite, etc., is said to be produced by physico-chemical action relating to surface tension. No reagent is necessary, and no chemical interaction results, although a slight rise of temperature has been noticed. Kerosene which was filtered through graded bauxite 30 to 60 mesh became water clear and, for practical purposes, free of sulphur. In process of time the bauxite in a filter becomes less active, but it can be rendered effective again by reheating. Thus it appears that, except for handling for reheating and sieving, there would be no loss of the bauxite, which can be used over and over again. Bauxite filters are now being installed in all modern oil refineries for the purification of kerosene. According to A. E. Dunstan (*The Petroleum Industry*, 1922, p. 182), Messrs. Hall Motor Fuel Company, Limited, have in recent years carried out this process in a slightly different way. They pass the vapour of petroleum over heated bauxite, and have demonstrated a very important point. This is that "cracked"[1] spirit, a most difficult substance to refine, is capable of simple and easy refining without any chemical treatment at all, and with the minimum of loss.

Considerable attention has been attracted to the fact that all kinds of bauxites are not equally efficient in the purification of kerosene. Also, much experimental work is in progress to discover why the most efficient kind of bauxite for kerosene purification is not equally effective in desulphurising petrol, and the reason of its failure when used for the purification of lubricating oil. Very little information is available regarding the results obtained in the recent investigations regarding the use of bauxite for the desulphurisation, etc., of all the petroleum distillates—from light spirit to the stiff wax. In most cases this research work is being conducted in the chemical laboratories of oil refineries.

Certain Indian bauxites, if partially calcined, have the property of removing those sulphur compounds, etc., which impair the colour, odour, etc., of kerosene. The Burma Oil Company have used bauxite for this purpose since 1908. This selective absorption of these undesirable impurities is thought to be similar in action to the familiar property of bone or wood charcoal for decolorising sugar solution, and the deodorising and clarifying power of Fuller's earth, floridin, aluminium hydroxide, etc., with regard to certain other liquids. Owing to the fact that Indian bauxite, which contains on an average 24 per cent. combined water, is more effective in this respect than French bauxite, which averages less than 12 per cent. of combined water, the opinion is that the action is dependent on surface tension phenomena. In either case, the raw material is unsuitable, and should be heated or steamed to a temperature of, roughly, 400° C. The porosity of the partially calcined Indian bauxite being greater than that of the French material, the Indian bauxite is more efficient for the removal of colour and sulphur derivatives from kerosene.

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[1] A term applied to distillation accompanied by decomposition, as a result of which hydrocarbons of high molecular weight are broken down into simpler molecules, coke and gas being usually simultaneously formed (*op. cit.*, p. 316).

This is well seen in the following table, which

"shows the percentage of moisture removable by roasting at 400° C., the ergometer rise (maximum) and the amount of total sulphur removed, all expressed in proportion with the worst sample of bauxite as unity. Direct proportionality—within experimental error—is seen to exist between these three sets of observations. The colour of the filtrate improves progressively with the activity of the bauxite, but the exact relationship between the two has not yet been ascertained." (Paper by A. E. Dunstan and others. See below.)

| Bauxite. | Water Removed at 400° C. | Ergometer Rise. | Sulphur Removed. | Colour of Filtrate, Degrees (Saybolt). |
|---|---|---|---|---|
| A . . . | 1 | 1 | 1 | 18 |
| B . . . | 1·1 | 1·3 | 1 | 18·5 |
| C . . . | 1·4 | 1·4 | 1·5 | 19 |
| D . . . | 1·9 | 2 | 2 | 24 |
| E . . . | 2·94 | 3 | 3 | 24 |
| F . . . | 2·9 | 3·3 | 3 | 24 |
| G . . . | 4·35 | 4·6 | 4 | 25 |
| H . . . | 4·42 | 4·8 | 5 | 25 |
| I . . . | 4·72 | 5·5 | 5 | 25 |

It is presumed that A is typical French bauxite (averaging 14 per cent. $H_2O$, of which probably only 3 to 5 per cent. is given off by roasting to 400° C.) with an ergometer reading of 8° C. rise in temperature in contact with kerosene. E would appear to be an Indian bauxite (with about 22 per cent. $H_2O$, of which 4 to 6 per cent. is given off by roasting to 400° C.) giving an ergometer rise of 23° to 28° C.; and H is evidently Indian bauxite (containing 30 per cent. $H_2O$, of which 6 to 8 per cent. is given off by roasting to 400° C.) having an ergometer rise of 41° C. It has been found that the temperature to which calcination is conducted greatly affects the activity of the bauxite. Below 400° C. the activity is weak, and above 700° C. the activity is seriously reduced. Also, calcined bauxite, if not used for some time, is found to have become less active, but this can be remedied by warming it up to 200° C. The temperature at which filtration is carried out is of importance if desulphurisation and decolorisation are both to be effected in one operation. This is well shown in the following table (paper by A. M. O'Brien quoted below):—

| Temperature of Filtration, °C. | Filtrate. | | |
|---|---|---|---|
| | Colour, 18 inch Cell (Lovibond). | | Sulphur, Per Cent. |
| — | Yellow. | Red. | |
| 10° | 1·5 | 0·40 | 0·091 |
| 20° | 2·2 | 0·09 | 0·087 |
| 30° | 2·9 | 0·10 | 0·885 |
| 40° | 4·0 | 0·58 | 0·084 |
| 50° | 6·0 | 0·70 | 0·080 |
| 60° | 6·9 | 0·60 | 0·077 |
| 70° | 7·4 | 0·50 | 0·075 |
| 80° | 8·0 | 0·90 | 0·072 |
| 90° | 9·6 | 0·70 | 0·068 |
| 100° | 10·4 | 1·0 | 0·065 |

This shows that the sulphur is best removed at warmer temperatures while the colour darkens with increased heating. It is thought that this colour effect is due to a polymerising effect of hot bauxite.

The subject of the use of bauxite for petroleum purification has been investigated by the Research Department of the Anglo-Perisan Oil Company (see paper by A. E. Dunstan and others, " Bauxite as a Refining Agent for Petroleum Distillation " ; also paper by A. M. O'Brien, " Technical Use of Bauxite in Connection with Petroleum Refining," in *Jour. Soc. Chem. Indus.*, vol. 43, No. 24, of 13 June, 1924, pp. 179 T to 189 T). Their work leads them to the opinion that :—

(1) Material such as roasted bauxite, containing large numbers of microscopic pores, is well known to possess an enormous surface area and consequent surface energy.

(2) When oil is allowed to come in contact with freshly ignited bauxite a considerable rise in temperature is observed, due to the surface energy being converted into heat energy.

(3) Bauxite obeys Freundlich's rule, which may be summarised as follows : $(x/m)^n$ is proportional to $c$, where (in this case) $x =$ per cent. of total sulphur adsorbed by bauxite, $m =$ wt. of bauxite per 100 parts of kerosene, $c =$ per cent. of sulphur in kerosene before filtration, $n =$ a constant.

They state also that—

(1) Bauxite is a colloidal absorbent of the first order for organic sulphur derivatives.

(2) Freshness of preparation gives best results, *i.e.* ignition immediately before use.

(3) Bauxite *per se* is a complete and sufficient refining agent for kerosene.

This is seen in the following normal cases :—

| Initial Colour. | Final Colour. | Per Cent. of Colour Removed. | $x/m$. |
|---|---|---|---|
| 100 | 52 | 48 | 9·6 |
| 58 | 32 | 45 | 5·2 |
| 42 | 21 | 50 | 4·2 |
| 14·2 | 5·5 | 61 | 1·74 |
| 4·6 | 2·2 | 52 | 0·45 |
| 3·5 | 1·7 | 52 | 0·34 |
| 1·7 | 0·8 | 53 | 0·17 |

(4) Other sulphurous distillates are also capable of purification by this process, as shown in the following table :—

| Material Tested. | Ergometer Rise, °C. |
|---|---|
| Crude untreated kerosene | 15·7 |
| Kerosene refined by hypochlorites | 16·4 |
| B.P. No. 1 petrol | 15·8 |
| Shell aviation spirit | 15·6 |
| Benzol | 18·2 |
| Xylol | 17·2 |
| Amylene | 13·8 |
| Medicinal liquid paraffin | 6·0 |

The present method of using bauxite may be divided into the following stages :—

(1) *Filtration.*—A predetermined volume of oil is filtered through a definite weight of bauxite.

(2) *Steaming-out.*—The filter is steamed out until no further kerosene can be removed economically.

(3) *Make-up.*—Fresh bauxite ground to size, and the required quantity added to make-up for losses in working.

(4) *Roasting.*—The fresh made-up bauxite and the spent material are roasted in excess of air to remove moisture, the last trace of kerosene, and firmly retained organic matter and carbon, thus freeing the pores for a new run.

The rate of filtration is of less importance in the removal of the sulphur than it is for decolorising. A slower is better for the latter. The size of the particles is also important, as seen below :—

| Mesh of Bauxite. | Ergometer Rise. |
|---|---|
| Held on 10 | 7·5 per cent. |
| „ 10-20 | 9·1 „ „ |
| „ 20-30 | 13·4 „ „ |
| „ 30-40 | 15·7 „ „ |
| „ 40-60 | 15·3 „ „ |
| „ 60-70 | 15·6 „ „ |
| „ 70-90 | 15·6 „ „ |
| Passing 90 | 12 „ „ |

A recent development has been established by O'Brien. The ground bauxite is charged into the container, and there heated by means of superheated steam to a temperature not lower than 350° C., after which it is cooled by passing dried air through it. The liquid to be refined is then passed through the filter, the quantity having been previously determined. The bauxite charge is afterwards subjected to steam, aided by the vacuum pump, and when fully drained is again treated with superheated steam at a temperature of 350° C. for regeneration, as previously stated. These operations are carried on alternately.

However, there is little doubt that the enormous saving in purification costs that might be effected by the successful application of bauxite for all the petroleum distillates is an incentive to further investigation. Until a bauxite is actually tested, it appears difficult to say how efficient it may prove for the purification of kerosene. The chemical analysis gives practically no clue to the value of the bauxite for this purpose. So far, the Indian high combined-water type of bauxite appears to have proved most suitable, and it is thought that this is due to the microcellular structure which must result when this bauxite is ignited preparatory to its use in the kerosene filter.

The demand for bauxite for oil purification becomes larger year by year, and would be very considerable if bauxite was, by suitable thermal treatment, made capable of purifying all petroleum distillates as efficiently as it treats kerosene. The waste, chiefly as dust, in crushing, heating, sieving, reheating, etc., although not large at first, steadily accumulates, so that perhaps some economy could be effected by collecting the dust and marketing it as "bauxite dross."

## REFRACTORIES.

**Bauxite Refractories.**—Owing to the large percentages of combined water which laterites contain, it is necessary thoroughly to calcine the material before moulding it into bricks. Some pisolitic varieties require special rotary calciners, as the material clogs and chokes and falls through the perforations of other kilns. This preparatory calcination at from 1200 to 1400° C. largely increases the cost of the firebricks. After calcination it is usual to mix one-sixth to one-third of its weight of plastic fireclay as a binding material. The mixture is moulded with water in the ordinary way, and burnt to the highest temperature obtainable in the kiln. Although the fusion temperature of these bricks is very high (1600° to 1900° C.), they have the objectionable property of cracking with changes of temperature. There is no objection to the use of typical laterite containing as much as 35 per cent. ferric oxide in some cases for this purpose; generally, however, the bauxite used for refractory purposes has a low iron content.

**Bauxite Bricks.**—The tendency of bauxite bricks to shrink continuously as long as they are exposed to a high temperature, militates against their employment as refractory material. After fusion in the electric furnace, bauxite is greatly improved, but must then be used with a special binder. By using magnesite in such proportion as to form $MgO . Al_2O_3$, calcining this mixture at a high temperature and grinding with a small quantity of the raw mixture, a very high grade, though expensive, refractory, capable of standing a temperature of 1800° C., is obtained.

**Refractory Linings to Furnaces.**—Bauxite linings have been found to meet the requirements of rotary Portland cement kilns. In these kilns the linings should not be too hard, or the cement does not coat the surface of the lining to protect it against corrosion. If, on the other hand, the linings are too soft, they are eroded by the cement itself.

Bonded bricks stand a pressure of 10,000 lb. (barely 5 tons) per square inch, and, though weak, they can be utilised in metal furnaces. Greater care is necessary in such cases regarding the composition of the laterite, as, although the material will easily withstand the temperatures and pressure to which it is likely to be exposed, it may not stand chemical corrosion at those high temperatures. During the refining of lead, for example, a scum rises to the top of the molten lead, and, wherever it comes in contact with the lining, it attacks it. As the scum is composed of highly basic oxides a basic lining is necessary. Consequently, laterite (or bauxite) not containing more than 10 per cent. of silica would answer very well. In a trial test, bauxite bricks lasted five times as long as ordinary firebricks. They have been used in place of magnesite with equally good results, and ferruginous laterite bricks have behaved better than the Stourbridge firebricks. Tested in white hot basic slag, the bauxite bricks showed the least corrosion of all the materials which were used. It is now frequently used as the lining material for basic open hearth steel furnaces.

These bauxite bricks, when exposed to intense heat, become converted into solid masses of emery of such extreme hardness that it is difficult to cut them out with steel tools. They are capable of resisting severe mechanical treatment, very high temperatures, and, if of suitable composition, powerful chemical corrosion. They have one objectionable character, and this is their liability to become cracked with alternations of temperature. Much, therefore, depends on the thoroughness of the preliminary roasting before the material is made up into bricks or blocks for furnace linings.

High alumina refractories are arbitrarily distinguished from other refractories containing alumina, by an alumina content of at least 58 per cent. Such refractories are ordinarily made from bauxite or bauxite and high-alumina clays—bauxitic clays, diaspore clays, and similar material. Ordinary bauxite bricks are made by mixing calcined bauxite or high-alumina clay with a bonding material such as fireclay, sodium silicate, or lime, shaping by hand or by brick machines, and burning in various types of brick kilns at a high temperature. Another class of bauxite refractories is made by fusing bauxite in an electric furnace and casting the molten material in moulds. The demand for this type of refractories is increasing, owing to the ever-growing needs for better refractories. Pure bauxite melts at about 1820° C., and pure alumina at about 2050° C. but the lower grades of bauxite brick melt at 1740° C. or less. The value of bauxite refractories depends upon their chemical inertness at high temperatures. In basic open-hearth steel practice bauxite brick should contain over 12 per cent. silica.

Recently high alumina refractories have been made more commonly from diaspore and high-alumina clays than from bauxite.

A short account of some tests on bauxite, corindite, and carborundum was given in a paper delivered before the Paris Academie de Sciences by Prof. de Chatelier and B. Bogitsch. The analyses were as follows :—

| | Pure Bauxite Brick. | Corindite. | Carborundum. |
|---|---|---|---|
| $Al_2O_3$ . . . . | 58·6 | 61·4 | — |
| $Fe_2O_3$ . . . . | 5·2 | 5·7 | 6·1 |
| $SiO_2$ . . . . | 29·5 | 24·0 | 12·9 |
| SiC . . . . | — | — | 79·2 |
| Free carbon . . . | — | 3·7 | 1·8 |
| Titanium . . . | 3·8 | 4·8 | — |
| Not estimated . . | 2·9 | 0·4 | — |

The corindite and the carborundum, when coarsely crushed, left the following residues on the screen :—

| | Corindite. | Carborundum. |
|---|---|---|
| Residue from 80 meshes to the sq. cm. . . . | 24 | 20 |
| Between 80 and 200 meshes per sq. cm. . . . | 27 | 40 |
| Between 200 and 5000 meshes per sq. cm. . . | 22 | 27 |
| Following pass through the screen of 5000 mesh . | 27 | 13 |

The samples investigated were :—

(1) Pure bauxite brick, manufactured industrially, moulded under pressure and baked at 1300° C. in a large kiln.

(2) Corindite agglomerate containing 10 per cent. of crude bauxite.
(3) Corindite agglomerate containing 10 per cent. of kaolin.
(4) Corindite agglomerate with 2 per cent. of a syrupy solution of sodium silicate.
(5) Corindite agglomerate with 6·50 per cent. of a syrupy sodium silicate solution.
(6) Carborundum agglomerate with 10 per cent. of kaolin.

The mixture for obtaining the blocks contained the quantity of pure water necessary to give a plastic paste ; they were then moulded by hand and baked for three hours at 1200° C. (in the case of corindite) and 1400° C. (in the case of carborundum). The crushing strengths in the hot state were measured in a special apparatus which had previously been used for similar tests. The rate at which the load was applied was 0·5 kg. per sec. (1·1023 lb. per sec.) :—

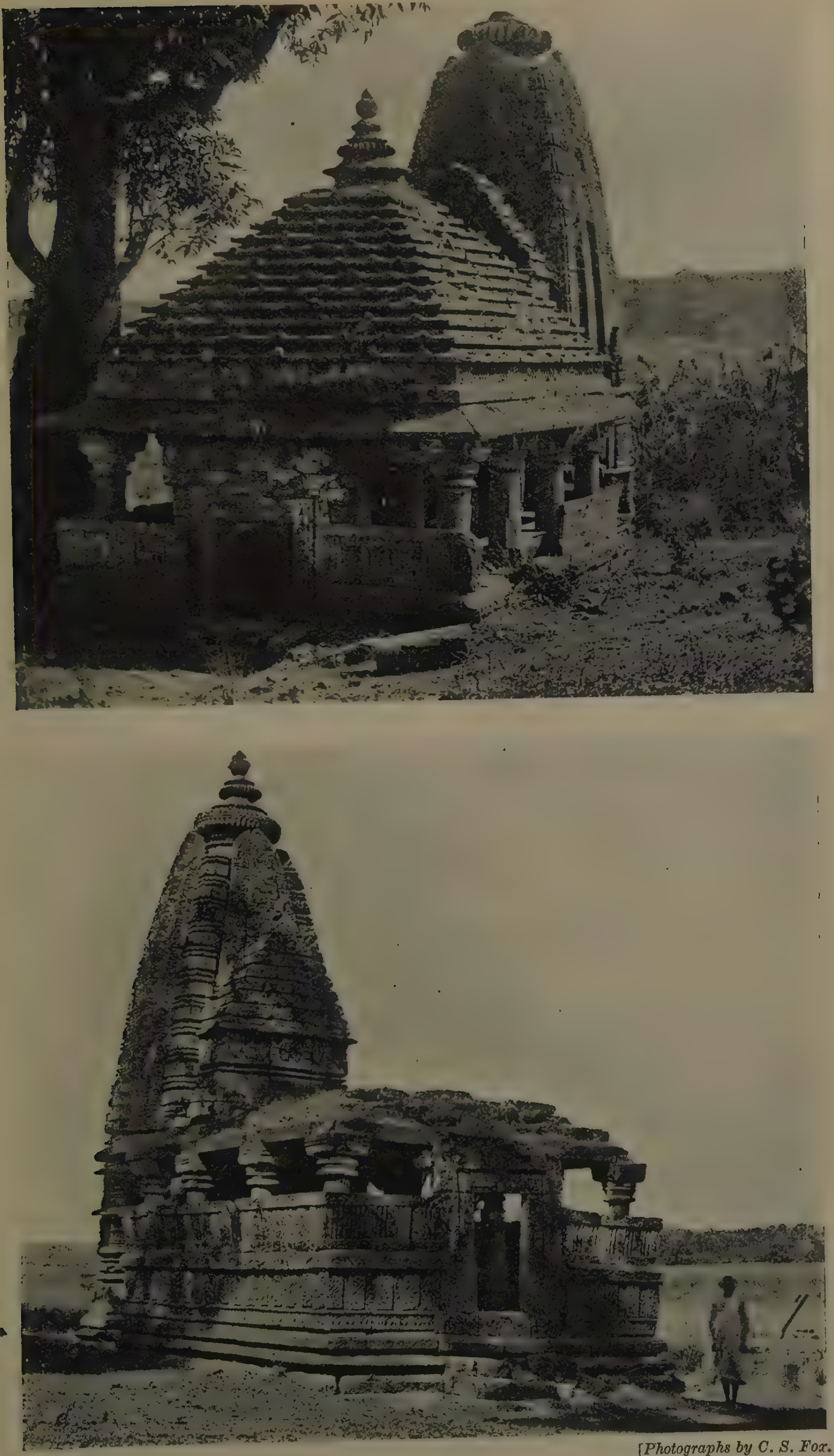
Crushing Strength of Refractory Materials—Lb. per Sq. In.

| Sample. | 20° C. | 1000° C. | 1200° C. | 1300° C. | 1400° C. | 1500° C. | 1600° C. |
|---|---|---|---|---|---|---|---|
| 1 | 2844·00 | 2560·14 | 1038·28 | 483·58 | 256·01 | (170·67) | (142·23) |
| 2 | 611·59 | — | 71·12 | — | (28·45) | — | — |
| 3 | 782·26 | — | 212·34 | 128·00 | — | (28·45) | — |
| 4 | 497·80 | — | (56·89) | — | — | — | — |
| 5 | 583·14 | — | (85·34) | — | — | — | — |
| 6 | 2033·89 | 1564·53 | 270·24 | (113·78) | (99·56) | (85·34) | (71·12) |

The accompanying table gives the crushing strength in pounds per square inch. The values in parenthesis refer to material which had become plastic and consequently had no further crushing strength. The figures given thus show the load reached at the moment when the sample had been crushed to one-third of its height for the speed of stressing of 0·5 kg. (= 1·1023 lb.) per sec.

All these products, therefore, became plastic at temperatures ranging between 1200° and 1500° C. For this reason they cannot be used in the construction of open-hearth furnace arches, the temperature of which exceeds 1600° C. Carborundum and alumina, which are perfectly intact at these temperatures, swim in a molten magma, which allows the grains to slide on one another. There is no longer any cohesion in the mass. At the same temperatures silica, although much more fusible, resists perfectly because the crystallisation of the tridymite gives rise to a network, in the centre of which the molten mass lodges without, however, modifying the continuity of the network. Alumina, therefore, behaves like magnesia ; in spite of its infusibility, it gives bricks which easily give under pressure when they are hot. It will also be seen that agglomeration with sodium silicate is less advantageous than agglomeration

PHOTOGRAPHS XVII. AND XVIII.



[*Photographs by C. S. Fox.*

Ancient (Jain) Temples at Armakantak, India, Built of Bauxite.

The blocks, set without mortar, show the chisel marks still sharp and fresh-looking.

or briquetting with kaolin. Sodium silicate may, however, be used for laboratory furnaces, where the temperature does not exceed 1400° C., because the walls have no stress to withstand.

The authors were able, by experimenting, to obtain aluminous products which showed a much greater degree of strength when hot than the preceding ones, by taking pure alumina and adding the strict quantity of agglomerant necessary to harden them by kiln-firing. Alumina calcined industrially was used, the following being the final figures :—

| | Per cent. | Per cent. |
|---|---|---|
| Alumina | 80 | 90 |
| White bauxite | 20 | — |
| Kaolin | — | 10 |
| Totals | 100 | 100 |

These mixtures each contained 95 per cent. of alumina. When first baked they contracted considerably and split in every direction. The material is first calcined at 1700° C. ; it is then crushed into coarse sand, and afterwards rebriquetted with one-quarter of its own weight of the same crude mixture. It is then rammed into blocks under pressure, and baked at 1700° C. In this way blocks are obtained which do not commence to soften at even 1600° C. At this temperature their crushing strength is 20 to 40 kg. per sq. cm., or 284 to 568 lb. per sq. in.

**Sugar Refining.**—Colloidal aluminium hydroxide has long been used for decolouring sugar solutions. The bisulphite of aluminium was used as long ago as 1885 for the purification of beet sugars. It seems likely that the use of bauxite in petroleum refineries originated from this analogy.

Bauxite has also been found suitable for the decolorisation of sugar and other hydrocarbon solutions, so that a large field for research is open, the successful exploitation of which would create a further demand for bauxite. However, colloidal alumina is thought to be more effective than either bauxite or Fuller's earth for the desulphurisation and decolorisation of mineral oils, etc., so that it is possible that the economy might be effected by preparing cheap pure colloidal alumina from bauxite.

# CHAPTER IX.

## THE ALUMINIUM INDUSTRY.

### INTRODUCTORY.

**Relative Abundance of Aluminium.**—Although aluminium is the most abundant of all metals, it is only within the last twenty-five years that it has become one of the metals of commercial importance. The element is of such common occurrence, that it would be impracticable to tabulate a list of all the minerals and rocks in which it is present. There are at least a hundred minerals which are essentially compounds of aluminium. All the important rocks, with the exception of pure limestones and sandstones, contain it as an essential constituent. Yet, in spite of this widespread occurrence, aluminium is never found native. It combines readily with oxygen; consequently, with the exception of certain rare fluorides, only the oxidised compounds of aluminium are known to exist in nature. From an economic point of view, these may be grouped as follows:—

(1) *Fluorides.*—*Cryolite* ($Na_3 . Al . F_6$), containing 32·8 per cent. Na, 12·8 per cent. Al, and 54·4 per cent. F.

(2) *Hydrates.*—*Diaspore* ($Al_2O_3 . H_2O$), with 85 per cent. $Al_2O_3$ and 15 per cent. $H_2O$. *Gibbsite* ($Al_2O_3 . 3H_2O$), with 65·4 per cent. $Al_2O_3$ and 34·6 per cent. $H_2O$. *Bauxite*, which is not a mineral, and contains colloidal hydroxides of aluminium and ferric iron in varying proportions, but not less than 50 per cent. $Al_2O_3$ and less than 10 per cent. $SiO_2$ as an impurity.

(3) *Oxides.*—*Corundum* ($Al_2O_3$).

(4) *Phosphates.*—*Turquois* ($AlP_4O . Al(OH)_3 + H_2O$), with 32·6 per cent. $P_2O_5$, 46·8 per cent. $Al_2O_3$, and 20·6 per cent. $H_2O$.

(5) *Silicates.*—*Anorthite* ($CaO . Al_2O_3 . 2SiO_2$), with 43·2 per cent. $SiO_2$, 36·7 per cent. $Al_2O_3$, and 20·1 per cent. CaO. *Labradorite* contains, roughly, 53·7 to 49·3 per cent. $SiO_2$, 29·6 to 32·6 per cent. $Al_2O_3$, 11·8 to 15·3 per cent. CaO, and 4·9 to 2·98 per cent. NaO. *Leucite* ($K_2O . Al_2O_3 . 4SiO_2$), containing only 23·5 per cent. $Al_2O_3$, but as much as 21·5 per cent. $K_2O$, and 55 per cent. $SiO_2$. *Cyanite* (sillimanite and andalusite have the same composition, *i.e.* $Al_2O_3SiO_2$), with

63·2 per cent. $Al_2O_3$ and 36·8 per cent. $SiO_2$. *Kaolinite* ($2H_2O \cdot Al_2O_3 \cdot 2SiO_2$), with 39·5 per cent. $Al_2O_3$, 46·5 per cent. $SiO_2$, and 14 per cent. $H_2O$.

(6) *Sulphates.*—*Alunite* (alumstone) ($K_2O \cdot 3Al_2O_3 \cdot 4SO_3 \cdot 6H_2O$), containing 37·0 per cent. $Al_2O_3$, 38·6 per cent. $SO_3$, 11·4 per cent. $K_2O$, and 13·0 per cent. $H_2O$. *Alunogen* ($Al_2(SO_4)_3 \cdot 18H_2O$), and the various but rare natural *Alums*, kalinite ($KAl(SO_4)_2 + 12H_2O$), Tschermigite ($NH_4 \cdot Al(SO_4)_2 + 12\,H_2O$), and Mendozite ($NaAl(SO_4)_2 + 12H_2O$).

Among the above-mentioned mineral substances the material bauxite is by far the most important as an ore of aluminium, but several others are of considerable commercial value, either for use in the reduction of alumina (*i.e.* cryolite) made from bauxite, or for the other elements which they contain (*i.e.* alunite and leucite for their potassium). Attempts have recently been made to use clays (kaolinite) of high grade and labradorite (felspar) as ores of aluminium in place of the substance bauxite, but the processes so far evolved, although successful, have not been brought to a stage for commercial employment.

Rough guesses, based on some determinative work, have been made regarding the importance and relative proportions (by weight) of the minerals which compose the rocks of the earth's crust. The most recent of these estimates (see *Economic Aspects of Geology*, by C. K. Leith) gives the following :—

| | |
|---|---|
| Feldspars | 49 per cent. |
| Quartz | 21 ,, ,, |
| Augite<br>Hornblende<br>Olivine | 15 ,, ,, |
| Mica | 8 ,, ,, |
| Magnetite | 3 ,, ,, |
| Titanite<br>Ilmenite | 1 ,, ,, |
| Kaolin<br>Limonite<br>Dolomite<br>Hematite<br>Calcite<br>Gypsum, etc. | 3 ,, ,, |

In chemical analyses the aluminium percentage in a mineral substance is usually estimated as the oxide, alumina. Dr. Clarke (*U.S.G.S.*, *Bull.* No. 695, 1920, p. 33) gives the average composition of the rocks of the earth's crust (the lithosphere only) as follows :—

| | | |
|---|---|---|
| $SiO_2$ (silica) | 59·77 | per cent. by weight. |
| $Al_2O_3$ (alumina) | 14·89 | ,, ,, |
| $Fe_2O_3$ (ferric oxide) | 2·69 | ,, ,, |
| FeO (ferrous oxide) | 3·39 | ,, ,, |
| MgO (magnesia) | 3·74 | ,, ,, |
| CaO (lime) | 4·86 | ,, ,, |
| $Na_2O$ (soda) | 3·25 | ,, ,, |
| $K_2O$ (potash) | 2·98 | ,, ,, |
| $H_2O$ (moisture, etc.) | 2·02 | ,, ,, |
| $TiO_2$ (titania) | 0·77 | ,, ,, |
| All other constituents as oxides | 1·64 | ,, ,, |
| Total | 100·00 | ,, ,, |

Dr. Clarke (*op. cit.*, p. 35) enumerates the order and relative percentages of the elements composing the earth's crust (lithosphere only). They are :—

| | | |
|---|---|---|
| 1. Oxygen | 47·33 | per cent. by weight. |
| 2. Silicon | 27·74 | ,, ,, |
| 3. Aluminium | 7·85 | ,, ,, |
| 4. Iron | 4·50 | ,, ,, |
| 5. Calcium | 3·47 | ,, ,, |
| 6. Magnesium | 2·24 | ,, ,, |
| 7. Sodium | 2·46 | ,, ,, |
| 8. Potassium | 2·46 | ,, ,, |
| 9. Hydrogen | ·22 | ,, ,, |
| 10. Titanium | ·46 | ,, ,, |
| All other elements combined | 1·27 | ,, ,, |
| Total | 100·00 | ,, ,, |

In this table it is seen that aluminium is very nearly twice as abundant as iron ; while the other metals of commerce—copper, lead, zinc, etc.—constitute such a small percentage of the earth's crust that their proportion can only be estimated by guessing. This has been done by Lindgren (*Mineral Deposits*) and by Eckel (*Coal, Iron, and War*, London, 1920). Their values have been incorporated in the subjoined table :—

| Name of Metal. | Percentage of the Earth's Crust. | Relative Abundance, Gold = 1. | Output in 1913 in Metric Tons. |
|---|---|---|---|
| Aluminium | 7·85 | 15,700,000 | 80,000 |
| Iron | 4·50 | 9,000,000 | 78,000,000 |
| Nickel | 0·023 | 46,000 | 33,000 |
| Copper | 0·0075 | 15,000 | 1,000,000 |
| Zinc | 0·0040 | 8,000 | 994,000 |
| Lead | 0·0020 | 4,000 | 1,155,000 |
| Tin | 0·0005 | 1,000 | 118,000 |
| Silver | 0·00001 | 20 | 7,000 |
| Gold | 0·0000005 | 1 | 682 |

Owing to trade complications which have followed the collapse of international exchanges since the war, the output for 1913 has been chosen as being a normal year. For comparison, however, the following approximate statistics (production of metals in metric tons) for 1920 and 1922 are attached.

| | Metric Tons. | |
|---|---|---|
| | 1920. | 1922. |
| Aluminium . . | 155,000 (over). | 117,000 |
| Iron (pig) . . | 60,000,000 (nearly). | 51,000,000 |
| Nickel . . . | 30,000 (about). | 12,000 |
| Copper . . | 1,000,000 (nearly). | 900,000 |
| Zinc . . . | 700,000 (over). | 700,000 |
| Lead . . . | 980,000 (nearly). | 1,200,000 |
| Tin . . . | 125,000 ,, | 132,000 |
| Silver . . . | 5,500 (about). | 7,000 |
| Gold . . | 520 (roughly). | 500 |

These figures show how small has been the production of aluminium with regard to its relative abundance when compared with any of the other common metals of commerce. The estimated world-production of aluminium, compiled from information published by the Imperial Mineral Resources Bureau, *The Mineral Industry*, and the *Metallgesellschaft* for the past few years, is shown in the following Table :—

ESTIMATED WORLD'S PRODUCTION OF ALUMINIUM.

(*In Metric Tons.*)

| Year. | United Kingdom. | Norway. | Germany, Austria *-Hungary, Switzerland †. | France. (*a*). | Italy (*a*). | U.S.A. | Canada. | Total. |
|---|---|---|---|---|---|---|---|---|
| 1911 | 5,000 | 900 | 8,000 | 10,000 | 800 | 18,000 | 2,300 | 45,000 |
| 1912 | 7,500 | 1,500 | 12,000 | 13,000 | 800 | 19,500 | 8,300 | 62,600 |
| 1913 | 7,600 | 1,500 | 12,000 | 13,503 | 874 | 22,500 | 5,900 | 63,877 |
| 1914 | 7,500 | 2,500 | 15,000 | 9,967 | 937 | 40,800 | 6,800 | 83,804 |
| 1915 | 7,100 | 2,300 | 12,000 | 6,020 | 904 | 44,900 | 8,500 | 81,724 |
| 1916 | 7,700 | 4,300 | 20,800 | 9,604 | 1,126 | 63,100 | 8,500 | 115,130 |
| 1917 | 7,100 | 7,600 | 26,000 | 11,066 | 1,740 | 90,700 | 11,800 | 156,006 |
| 1918 | 8,300 | 6,900 | 34,000 | 12,023 | 1,715 | 102,000 | 15,000 | 179,938 |
| 1919 | 8,100 | 3,100 | 31,500 | 12,200 | 1,673 | 81,600 | 15,000 | 153,173 |
| 1920 | 8,000 | 5,600 | 31,200 | 12,000 | 1,238 | 87,300 | 12,000 | 157,338 |
| 1921 | 5,000 | 4,000 | 22,000 | 10,000 | 744 | 28,750 | 6,000 | 76,494 |
| 1922 | 9,500 | 6,000 | 28,000 | 12,000 | 630 | 52,000 | 9,000 | 117,130 |
| 1923 | 9,000 | 14,000 | 29,000 | 12,000 | 1,500 | 97,000 | 16,500 | 179,000 |
| 1924 | 7,000 | 22,000 | 35,000 | 18,500 | 2,000 | 85,000 | 16,000 | 186,500 |

(*For references to table see opposite page.*)

| Year. | *Austria. | Year. | † Switzerland. |
|---|---|---|---|
| 1919 | 5,000 | 1915 | 10,000 |
| 1920 | 2,000 | 1516 | 12,500 |
| 1921 | 2,000 | 1917 | 15,000 |
| 1922 | 4,000 | 1918 | 15,000 |
| 1923 | 4,000 | 1919 | 15,000 |
| 1924 | 3,000 | 1920 | 12,000 |
| | | 1921 | 10,000 |
| | | 1922 | 12,000 |
| | | 1923 | 12,000 |
| | | 1924 | 19,000 |

It will be evident from all that has been said and from what follows that the discovery and extraction of aluminium in metallic form is of comparatively recent date as a metallurgical industry. This has been largely due to the physical and chemical difficulties involved. Even to-day it is a fact to be wondered at that a metal with so great an affinity for oxygen, with which it combines with considerable evolution of heat, is available for use in a practically pure form. Among the numerous aluminium-containing mineral substances only one—bauxite—has proved suitable on a commercial scale. Cryolite could be used, but the substance is far too valuable for this purpose. It is, however, utilised as a solvent for alumina in the electrolytic process now in vogue. Numerous attempts have been made to utilise other mterials, *e.g.* labrador felspar in Norway and Sweden ; clay in Germany ; leucite in Italy ; and, so it is said, alunite in America, but in nearly every case the expense involved leads to the financial embarrassment of the operating company. The factors involving the *interests* of the purchasers of alumina, *i.e.* the producers of aluminium, are considerable, and as long as these monopolistic companies possess deposits of easily procured bauxite, they will use bauxite.

**Other Raw Materials.**—Among the various other substances which have from time to time been experimented with, as possible ores of aluminium, may be mentioned the following :—

Cryolite, kaolin (clay), labradorite felspar, leucite, and alunite.

There is little doubt that if some of these minerals could be found in vast deposits in regions where no bauxite was available, and in close juxtaposition with cheap fuel and power, they would be very serious rivals. Cryolite is found in only one workable deposit in the world, and it is not too much to say that if this source of supply suddenly disappeared the present output of aluminium would be practically brought to an end. Leucite has an attractive potash content which, if the supplies were abundant, might pay for the extraction of alumina, but the deposits are strictly limited. Kaolinite, felspar, and alunite will be more attractive to the chemical industry than to producers of aluminium as long as the existing methods of reduction are used.

The following remarks may, however, be of interest :—

**Cryolite.**—This is a fluoride of sodium and aluminium, $3NaF . AlF_3$, which, when pure, should contain 12·8 per cent. aluminium, 32·8 per cent. sodium, and 54·4 per cent. fluorine. The natural mineral is, however, frequently found to be contaminated with small percentages of ferric or manganese oxide, lime and magnesia, and, sometimes, traces of vanadic and phosphoric acid. The mineral usually occurs as snow-white cube-like (monoclinic) crystals, with the appearance and lustre of ice (hence the names Ice-spar or *Eisstein*, and *Kryolith* from the Greek *Kryos*, frost, and *lithos*, a stone). The substance is brittle and soft—the hardness being, roughly, 2·5. The specific gravity is about 2·95 to 3·0. The refractive index is low, and small fragments of the mineral are barely visible when immersed in water. Little pieces of cryolite can be readily fused to a white enamel.

Before 1854 cryolite was a rare mineral, but then became available, and was largely used as an ore of aluminium. It has, however, been replaced for this purpose by the cheaper aluminium ore, bauxite. Aluminium reduction companies still use cryolite in the present electrolytic process as a solvent for the alumina (purified bauxite), from which the virgin metal is finally obtained. Cryolite is also used for the manufacture of sodium salts, enamels for ironware, opaline glass, and various other purposes.

The natural mineral is comparatively rare—only three well-known occurrences being quoted in the literature on this substance. These localities are (1) at Ivigtut, in South-West Greenland ; (2) Miask, in the Urals ; and (3) near Pikes Peak, in Colorado. Of these occurrences only one has been found workable on a commercial basis. This is the Ivigtut mine on the Arauk Fjord in Greenland (see paper by C. P. Bernard in *The Mining Magazine* for April, 1916, pp. 202-203). There is an earlier paper by J. W. Taylor in the *Quart. Jour. Geol. Soc.*, vol. xii, p. 140). The Ivigtut deposit has been worked for many years. The mineral occurs in the form of a pegmatitic vein in a grey gneiss, and is associated with galena, zinc-blende, chalybite, pyrite, arsenopyrite, fluorite, columbite, and cassiterite. The pegmatite is supposed to be genetically related to an intrusive porphyritic granite which is exposed in the vicinity of the deposit. The cryolite has been proved for a length of 600 feet, and is reported to be 200 feet wide at the surface. In 1916 it had been worked to a depth of 50 feet. It is mined in two grades—" white " and " black." The " white " ore averages 90 to 95 per cent. cryolite with galena, pyrite and siderite as impurities making up the remaining 5 per cent. It is largely shipped to Copenhagen by Oresunds Chemiske Fabriker, Kommanditselskat ved C. F. Jarl of Copenhagen, who are the selling agents for all countries except the United States of America. The " black " grade contains a lower percentage of cryolite, but in addition to the associated minerals of the " white " grade, it contains a large amount of fluorite (fluorspar). This ore is shipped to the Pennsylvania Salt Manufacturing Company of Philadelphia, Pa., who are said to be the sole agents in America. The Ivigtut deposits, of course, belong to the Danish Government, who have given a State concession to the Kryolith Mine and Handelsselskabet A/S of Copenhagen for mining the cryolite. The mining has been done by open-cut working.

The amounts of the shipments since 1914 have been as follows,[1] in metric tons :—

| | To U.S.A. | To Denmark. | Total. |
|---|---|---|---|
| 1914 . . | 4,139 | 7,373 | 11,512 |
| 1915 . . | 3,753 | 5,809 | 9,562 |
| 1916 . . | 3,773 | 9,812 | 13,585 |
| 1917 . . | 3,959 | 5,678 | 9,637 |
| 1918 . . | 1,916 | 8,802 | 10,118 |
| 1919 . . | 1,973 | 4,394 | 6,367 |
| 1920 . . | 5,024 | 8,904 | 13,928 |
| 1921 . . | 5,200 | 6,118 | 11,318 |
| 1922 . . | — | — | — |
| 1923 . . | — | — | — |

In 1914 the average value per metric ton in America was \$20.47. In 1919 the price was \$50.20, and in 1921 this type of cryolite was \$85.31 per metric ton.

In 1921 Danish cryolite was available in the United Kingdom at about £40 a long ton.

During recent years cryolite has been prepared synthetically, and large quantities of the artificial product are now available. Artificial cryolite is manufactured, under German patent No. 307525, of 23 January, 1917, by the Chem. Fabr. Goldschmieden H. Bergius & Co. It is prepared by subjecting a correct mixture of fluorspar, silica (sand), and sodium bisulphate to a red heat—

$$(2CaF_2 + SiO_2 + 4NaHSO_4 = SiF_4 + 2Na_2SO_4 + 2CaSO_4 + 2H_2O)$$

and absorbing the silicon fluoride thus produced by solid hydrated sodium sulphate—

$$(3SiF_4 + 2Na_2SO_4 + 2H_2O = SiO_2 + 2H_2SO_4 + 2Na_2SiF_6).$$

---

[1] See *The Mineral Industry* during 1921, vol. xxx, 1922, p. 224.

After removing any sulphuric acid or sodium bisulphate, the sodium silicofluoride is decomposed by fusing it with crystalline sodium carbonate in the proportion of 1 molecule of sodium silicofluoride to 4 molecules of sodium carbonate. This results in the formation of sodium fluoride, sodium carbonate, and silica. The silica is then filtered off—

$$(Na_2SiF_6 + 4Na_2CO_3 + 10H_2O = 6NaF + 4NaHCO_3 + SiO_2 + 8H_2O),$$

and cryolite is precipitated by adding sodium aluminate to the solution—

$$(6NaF + 4NaHCO_3 + NaAlO_2 = (NaF)_3AlF_3 + 4NaCO_3 + 2H_2O).$$

The importance of the cryolite used in the reduction of aluminium from alumina will be seen from the following extracts from *The Metallurgy of the Non-ferrous Metals* (pp. 567-569) :—

> The Bayer process is used for the preparation of the alumina from bauxite. The furnaces are steel shells, 12 feet long, 9 feet wide, and 5 feet high. They are lined with one layer of firebrick and an inner lining of carbon, leaving the working cavity about 8 feet long, 4 feet wide, and about 1 foot 8 inches deep. Each furnace will take 20,000 amperes at 7 volts, corresponding to 140 kilowats, and should produce about 300 lbs. of aluminium per day. Seventy furnaces are connected in series corresponding to an electromotive force of 500 volts. There will be six such units, or about 400 furnaces, running at the same time, giving a maximum yearly output of 44,000,000 lbs. of aluminium. The bath is to be the customary one of cryolite and alumina. . . .
>
> THE ELECTROLYTIC BATH.—This consists essentially of cryolite, as the electrolyte, containing $Al_2O_3$ in solution. It is heated solely by the electrolysing current, external heating having been completely given up. The composition of the electrolyte varies in different works. According to Professor Lodin,[1] at one French works it consists of cryolite, 36 ; aluminium fluoride, 44 ; fluorspar, 20 parts. The aluminium fluoride is obtained by treating pure clay with hydrofluoric acid, precipitating copper, etc., by $H_2S$, and crystallising the solution. Other works use simply mixtures of cryolite and fluorspar.
>
> Sodium chloride is sometimes added.
>
> The density of the bath must be lower than that of molten aluminium, in order that the metal may sink to the bottom as it is reduced. Cryolite saturated with $Al_2O_3$ when molten has a specific gravity of 2·35, that of molten aluminium being 2·54.
>
> It must also be fluid at about 900° to 950° C., the temperature at which electrolysis takes place.
>
> Cryolite melts at about 1000° C., but its fusion point is lowered by the addition of $Al_2O_3$, thus, according to Moldenhauer, when 10 per cent. is present it is 930° C., and with 20 per cent. 880° C. Cryolite will not dissolve more than 25 per cent. $Al_2O_3$.
>
> The nature of the electrolyte has been further investigated by P. Pascal and A. Jouniaux.[2] Their papers contain many important determinations, and are well

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[1] *Note sur la Fabrication Electrolytique de l'aluminium*, published by Dunot et Pinot, Paris.

[2] "Abstracts in Mineral Industry," 1914, p. 18, and 1915, p. 19 ; from *Bull. de la Soc. Chimique*, 1913, p. 639 ; *ibid.*, 1914, p. 312.

worthy of perusal. The chief results of their researches may be briefly stated as follows. The following melting-points are determined :—

| | |
|---|---|
| Cryolite | 977° C. |
| Fluorspar | 1361° ,, |
| Cryolite-fluorspar eutectic (74·6 per cent. cryolite) | 905° ,, |
| Cryolite-alumina eutectic (24 per cent. $Al_2O_3$) | 904° ,, |
| Fluorspar-alumina eutectic (26·9 per cent. $Al_2O_3$) | 1270° ,, |
| Cryolite-fluorspar-alumina eutectic (cryolite, 59 per cent. ; fluorspar, 23 per cent. ; alumina, 17·7 per cent.) | 868° ,, |

According to W. A. M. Knight, the melting-point of the cryolite-alumina eutectic (15·5 per cent. $Al_2O_3$) is 935° C.

The specific gravity of cryolite is 2·22 at 995° C., about 0·31 below that of aluminium at the same temperature.

Fluorspar increases rapidly the specific gravity of molten cryolite.

When 12 per cent. is present the increase is 0·10, and with 25 per cent. the increase is 0·26.

The addition of alumina to cryolite reduces the specific gravity when in quantities less than 20 per cent. With 24 per cent. the specific gravity is 2·26 at 935° C., which is still lower than that of aluminium at the same temperature.

The current density is 700 amperes per square foot of cathode surface, *i.e.* the horizontal cross-section of the bath (Borchers).

Professor Lodin [1] calculates the current density as varying between 1·5 and 3 amperes per square cm. (9 to 19 per square inch) of anode section.

The voltage drop is 8 to 10 volts per bath.

The Operation.—The anodes are lowered until they will form an electric arc with the bottom of the furnace; some of the mixture of cryolite and alumina, or in some works cryolite alone, is charged in and the current started. As soon as this has melted more additions of the mixture are made from time to time, the anodes being gradually raised, until the furnace is full.

Additions of alumina are then made, as required, to keep the bath of the proper strength. If an excess is added the bath will become pasty and the aluminium will not settle, but will rise and cause short-circuiting ; whilst if there is insufficient, the voltage will rise to 15 volts or more, the fluorides will be decomposed, and the composition of the bath deranged. The normal voltage should be from 8 to 10 volts, and an abnormal rise is indicated by an incandescent lamp connected from anode to cathode.

If too much aluminium is allowed to accumulate in the furnace, the temperature rises, sodium is liberated, and burns at the surface.

In normal working the bath is covered with a solidified crust of electrolyte, upon which the alumina to be added is spread, so that it may be heated, and dried if necessary, and is stirred into the bath as required. In some cases the crust is covered with a layer of charcoal, upon which the alumina is spread as usual.

The aluminium is tapped from the bath every two or three days, some, however, is left in, as it has been found that the aluminium collects best on a bed of the molten metal.

The mean output of a furnace, 10 feet by 4 feet, with a working cavity about 15 inches deep, is about 1 cwt. of aluminium per day.

The cryolite, or other double fluoride of aluminium and sodium, serves only as a solvent for the alumina, which alone is electrolysed. Aluminium is produced at the cathode, and oxygen at the anode. The anode is attacked by the oxygen, which combines with the carbon, forming CO and some $CO_2$.

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[1] *Min. Ind.*, 1910, p. 20.

In normal working the consumption of anodes, not reckoning the unused butt-ends, is 60 to 65 per cent., of cryolite 12 to 20 per cent. of the weight of aluminium produced, and about 2 lbs. of $Al_2O_3$ are used in the production of 1 lb. of aluminium.

**Kaolin.**—The commonest aluminium compound is the substance known as "kaolinite," a hydrated silicate of aluminium, $H_4Al_2Si_2O_9$, which is present in all ordinary clays. When pure its composition is calculated to be 39·5 per cent. alumina, 46·5 per cent. silica, and 14·0 per cent. combined water. The purest natural form of this substance is, from an economic standpoint, probably china clay. The constituent kaolinite is thought to occur in a colloidal form in plastic clays. It is considered to form as the result of the hydration of the felspar in felspathic rocks which have undergone decomposition. The best example of this alteration is that of the china clay deposits which occur in close proximity to masses of decomposed granite.

The alumina percentage in clays varies greatly, and appears to influence the physical character of the many varieties of clay—for example, glacial clays contain, roughly, 10·0 alumina; normal residual clays average 18 to 22 per cent. alumina; certain fire clays contain more than 26 to 28 per cent. alumina; china clays of great purity, 37·6 per cent. alumina; and the exceptional Ayrshire bauxite clay gave as much as 50 per cent. alumina in some analyses. Owing to the appreciable percentage of alumina in many large favourably located deposits of clay, it has been thought that a process might be devised for the extraction of alumina from such clays. Numerous experiments have been conducted in this connection, and a considerable degree of success is reported to have attended the labours of the investigators in Germany, Norway, and Japan (see "La Préparation de l'Alumine à partir de l'Argile," in *Rue de Metallurgie*, of August, 1920). It is a translation by M. Pierre Barrand of a paper by Dr. I. V. Gerber in the *Zeitschrift für Electrochemie und angewandte Physikal Chemie*, 25, 1919). However, no satisfactory commercial process appears to have been established (see "Production of Alumina from Clay: Tests on the Miguet Process," by Clyde F. Williams and Clarence E. Simms: *Reports of Investigation*, Serial No. 2393, September, 1922, Bureau of Mines, U.S.A.).

The separation of the silica by artificial means must always be a handicap to a high-percentage alumina clay when used in competition with bauxite for the production of pure alumina. It is the opinion of some investigators that this handicap will not be so serious when a process is devised for the direct production of aluminium, or an aluminium-silicon alloy, from the raw material. The recent experiments at the Badin (Whitney, N.C.) works of the Aluminium Company of America have shown that aluminium, by vaporisation in a blast furnace, can be obtained directly from calcined bauxite, but the process, as conducted in 1921, was not commercially attractive.

**Felspar.**—There is an important group of rock-forming minerals known under the general name of felspar. They consist of silicates with alumina, in combination, as an essential constituent. The common felspars are enumerated below :—

| Name. | Chemical Formula and Composition. | Specific Gravity and Melting-Point. | Remarks. |
|---|---|---|---|
| Orthoclase | $K_2O . Al_2O_3 . 6SiO_2$<br>16·9%, 18·4%, 64·7% | 2·56<br>1150° C. (?) | — |
| Microcline . | Ditto. | Ditto. | — |
| Albite . | $Na_2O . Al_2O_3 . 6SiO_2$<br>11·8%, 19·5%, 68·7% | 2·62<br>1220° C. (?) | — |
| Oligoclase . | $Ab_6Au_1$ to $Ab_3Au_1$<br>$Al_2O_3$ about 24% | 2·68<br>1260° C. to 1360° C. | These are isomorphous mixtures of albite and anorthite. The ratio of albite to anorthite is in excess of 1 for oligoclase and andesine, and less than 1 for labradorite and bytounite. |
| Andesine . | $Ab_3Au_1$ to $Ab_1Au_1$<br>$Al_2O_3$ about 27% | 2·71<br>1360° C. to 1490° C. | |
| Labradorite | $Ab_1Au_1$ to $Ab_1Au_3$<br>$Al_2O_3$ about 30% | 2·74<br>1490° C. to 1520° C. | |
| Bytounite . | $Ab_1Au_3$ to $Ab_1Au_6$<br>$Al_2O_3$ about 33% | | |
| Anorthite . | $CaO . Al_2O_3 . 2SiO_2$<br>20·1%, 36·7%, 43·2% | 2·76<br>1550° C. | |

The potash felspars are invariably present in acid igneous rocks. The soda felspars are characteristic of the Intermediate and Basic igneous rocks. Anorthite is peculiar to certain exceptional igneous rocks of the Basic to Ultra-basic types.

The value of the potash in orthoclase felspar has long been recognised, and any favourably located extensive occurrence of this mineral offers a field of investigation with a view to the commercial extraction of the potash for fertiliser purposes. In a similar way the percentage of alumina has proved attractive to industrial chemists for the isolation of the alumina. This is particularly true if very large occurrences of a high alumina felspar, such as labradorite or anorthite, are found in an area where no bauxite is known, and where power from hydro-electric stations, as in Norway, can be cheaply supplied. A chemical process has recently been devised for the treatment of the great segregations of labradorite which occur in certain areas of Norway. The felspar is decomposed by a 30 per cent. solution of nitric acid, and any iron in the solvent is removed, and the filtrate is evaporated to dryness, yielding a residue of alumina from which the nitrates of calcium and sodium are subsequently removed and utilised for agricultural purposes (see paper on the Goldschmidt process by L. Hawkes in *Nature* for 23 October, 1919). However, the alumina prepared by this process is evidently not able to compete in price with imported alumina made from bauxite, as the experimenting company appear to have been absorbed by the Aluminium Company of America (see p. 246).

**Leucite.**—Known as one of the felspathoid minerals, is, relatively speaking, of rare occurrence, being normally found in certain lavas. It is a potassium aluminium silicate, $KAl(SiO_3)_2$, averaging 55·0 per cent. silica, 23·5 per cent. alumina, and 21·5 per cent. potash. The hardness of the mineral varies between 5·5 and 6, and the specific gravity averages 2·45 to 2·50.

Leucite appears to occur in sufficient quantity for exploitation as such only in Italy, in association with the lavas of Vesuvius and Mt. Somma. Its rarity, however, militates against its use as a regular ore of aluminium. The chief attraction is naturally the high potash content which might be extracted for the preparation of a fertiliser, and, incidentally, the alumina may be recovered as a by-product for use in the chemical or aluminium industry. However, the potash supplies in Germany and the alumina available from bauxite must always render leucite unattractive for treatment and extraction of these two constituents.

**Alunite** or alumstone is a hydrated basic sulphate of aluminium and potassium, $KAl_3(SO_4)_2(OH)_6$, which theoretically contains 38·6 per cent. sulphur trioxide, 37·0 per cent. alumina, 11·4 per cent. potash, and 13·0 per cent. combined water. Alunite is a greyish white substance, having a pearly lustre, and occurring in massive form with a micro-crystalline (tri-clinic) texture. When heated it decrepitates, first yielding water and then sulphurous and sulphuric oxides at higher temperatures. The mass of the substance is infusible, even when heated in a blow-pipe flame on charcoal.

Alunite has been found in several localities in various parts of the world. The best-known occurrences are those of Bullah Delah, in New South Wales, Australia ; Tolfa, near Rome, Italy ; Benahadux, in Almeria in Spain ; and near Marysvale, in Utah, U.S.A. (see Thorpe's *Dictionary of Applied Chemistry*, vol. i, 1921, p. 180). Its chief use has been in the manufacture of alum, but during recent years attempts appear to have been made to utilise alunite for the preparation of alumina for subsequent reduction to aluminium. Except in rare cases, in which the alumina may be obtained as one of two or more products, it is difficult to understand how alunite can compete with cheap bauxite as an ore of aluminium. It is known that if alunite is strongly heated it is converted into a mixture of alumina and potassium sulphate, and in this condition it is useful as a potash fertiliser. The high percentage of potash in the crude material is always an attractive constituent.

### HISTORICAL SUMMARY.

The name *Aluminium* is of Roman origin. Pliny was familiar with a substance with an astringent taste which he described as *alumen*. The *alumen* of Rocca has long since been identified with a pure form of common rock-alum—sulphate of aluminium and potassium—as we know it (see *Aluminium*, by G. Mortimer, London, 1919, p. 2). As early as 1722 there is a record of an investigator, F. Hoffman, expressing the opinion that alum contained an individual substance as its base. Then, in 1760, the chemist, T. Baron de Henouville, considered it not too venturesome to predict that a day would come when the metallic nature of the base of alum would be incontestably proved (see his *Memoires de l'Academie Royale*). Sir Humphry Davy also continued the search for the elusive metal. In 1808, after many attempts, even with his great electric battery, he wrote :—

> "Had I been so fortunate as to have obtained more certain evidences on this subject and to have procured the metallic substances I was in search of, I should have proposed for them the names 'silicium,' 'alumium,' 'zirconium,' and 'glucium.'" (*Phil. Trans. Roy. Soc.* (London), 1808.)

Frederick Wohler, of Gottingen, in 1827, by modifying an unsuccessful experiment performed by Œrsted three years before, succeeded in obtaining an impure form (a grey powder) of the metal. He successfully reduced aluminium chloride with pure metallic potassium ; Œrsted had used potassium amalgum, the mercury present causing the failure of his experiment (see Mortimer, *op. cit.*, p. 3). Continuing his attempts at various times, Wohler finally produced a malleable bead of the metal in the year 1845. With this bead many of the physical and chemical properties of the metal were determined, but it was known that even this metal was not pure. A few years later, in 1854, Henri Sainte Claire Deville, of the École Normale, Paris, unknowingly repeated Wohler's experiment and obtained the metal. He was quick to grasp the practical application of the method for industrial purposes. With further work he obtained a comparatively pure metal and established a commercial process, using metallic sodium for the extraction of aluminium from its chloride. Deville was immediately followed by other inventors in France and elsewhere. In the same year, 1854, Dr. H. Percy obtained aluminium by reducing cryolite with metallic sodium, and Bunsen produced the metal by the electrolysis of aluminium-sodium chlorides. In the following year H. Rose first separated aluminium by the electrolysis of cryolite. In 1856, Deville and Bunsen tried to develop the electrolytic method, using only cryolite, but failed to obtain the required amount of electric current for a practical process. The Deville chemical reduction process was first developed at Javal, then at La Glacière (near Paris), next at Nanterre, and finally transferred to Salindres (in Gard), where the works were taken over by Messrs. Pechiney. All these early processes were chemical processes conducted at comparatively moderate temperatures.

The first aluminium works established in England were those of F. W. Gerhard, at Battersea, in 1858. Other works were built later, such as those at Greenock, Wallsend, Oldbury, etc.

The first few ounces of aluminium extracted by Deville were presented, as a toy, to the Prince Imperial, then a baby. In 1855 the metal was available in Paris for 1000 francs a kilogram. The price in this country about the same time was 450s. a lb. In spite of keen competition and numerous other modifications, the Deville process continued to be the chief method of production for thirty years. During the period 1855 to 1885 it is computed that over 100,000 lb. (nearly 50 tons) of aluminium had been placed on the market. The price had meanwhile fallen to 28s. a lb., followed soon after by a further reduction to 30 francs per kilogram.

About this time, 1886, the development in dynamo-electric machinery had reached a stage of great efficiency. The brothers E. H. and A. C. Cowles had already established works for the direct smelting of alumina with carbon in the presence of copper in an electric furnace. They were operating at Lockport, New York, and at Milton, in Staffordshire. Their product was, however, an aluminium bronze. Meanwhile, Charles M. Hall, of Oberlin, Ohio, and P. T. L. Hérault, in France, had simultaneously conceived the idea of obtaining aluminium by the electrolysis of alumina dissolved in a bath of molten cryolite. The effect of the electrolytic process, or, as it is generally called, the Hall-Hérault process, was soon felt by the other manufacturers of aluminium.

By 1888 both Hall and Hérault had erected successful works. The first plant of the Hall process was worked by the Pittsburg Reduction Company, Limited, at Pittsburg, Pa., in America. In 1894 the first Niagara Falls works were erected, followed soon after by a second plant, and then, in 1903, works at Massena Springs, N.Y. The Shawinigan Falls plant in Quebec, Canada, was built about 1900. The Pittsburg Reduction Company was transformed into the Aluminium Company of America in 1909, a few years after the death of Captain Hunt, a pioneer of the former company. The Hérault process was in operation at various works in France and Switzerland in 1888. La Société Électrometallurgique was working in a small way at Froges, near Grenoble (Isère). The old Bernard works at St. Michel, which had been using the Minet process, were acquired by Messrs. Pechiney in 1897, and equipped with Hérault furnaces. Later (1900) large works were built at La Praz, near Modane, followed by another plant at St. Michel de Maurienne, in Savoie.

The Société Metallurgique Suisse were also operating in 1888, and were joined soon after by the Allgemeine Electricitäts Gesellschaft (the A.E.G.), and converted into the well-known Aluminium Industrie-Aktien-Gesellschaft of Neuhausen.

With competition so keen expansion was rapid; the output increased and prices fell. Already in 1892 aluminium was quoted at 7s. a lb. The total production for the period 1855 to 1900 has been estimated at 20,000 tons. The annual rate of production is said to have exceeded 5000 tons in 1900, while the prices in the same year were 3 francs per kilo (retail), and 2 marks per kilo (wholesale)—roughly 1s. a lb.

The British Aluminium Company, Limited, had come into being in 1895. They were operating reduction works at Foyers in Inverness-shire, and had erected an alumina factory (Bayer process) at Larne (Ireland). For a few years (till 1899) they purified the Irish bauxite of Co. Antrim, but subsequently arranged for supplies of bauxite from the south of France. The chemical works at Greenock (Scotland), and the Cowles plant at Milton, were also acquired by this English company.

Progress continued at a great pace. Bauxite occurrences were discovered in rapid succession in various parts of the world—India, Australia, South America, the Balkans, etc. Synthetic cryolite was commercially available, and great economies had been effected in the preparation of alumina, carbon electrodes, and in the reduction of the metal. The total output of aluminium for the decade 1901 to 1910 is computed at 150,000 tons. The rate of production in 1910 had attained the large total of 50,000 tons annually, and the average price of aluminium in that year was nearly £60 a ton—about 6d. a lb.—the lowest price on record.

The steady fall in prices appears to have led the Société Électrometallurgique Française de Froges, La Compagnie des Produits Chimiques d'Alais et de la Camargue, Aluminium Industrie-Aktien-Gesellschaft of Neuhausen, the Pittsburg Reduction Company of Pennsylvania, and, finally, the British Aluminium Company, to form an International Aluminium Syndicate in 1904. They hoped to control the market and obtain higher prices; over-production, however, followed, and the subsequent trade depression caused a great fall in prices. The Syndicate was dissolved in 1909, after an existence of five years.

After great efforts, a recovery was effected, and the foundations of the present five great groups of aluminium producers were effectively laid. The five groups are: (1) L'Aluminium Francaise; (2) The Aluminium Company of America; (3) The British Aluminium Company, Limited; (4) the Swiss (A.E.G.); and (5) the German, State-run reduction works.

During the next ten years, 1911 to 1920, largely due to the requirements of the Great War, the out-turn of aluminium totalled over a million tons. Prices were naturally inflated—£225 a ton in 1917—but eventually, in 1920, fell back to about 1s. a lb., the price of twenty years before.

The reduction in price has continued, and business can be done for £90 a ton for 98 to 99 per cent. virgin metal. It will be seen from the accompanying statistics (table, p. 220), that the average annual production of aluminium from all countries exceeds 150,000 tons. It will also become clear from Chapter X., which deals with the ownership, location, and capacity of the various reduction works in operation or in progress of erection, that in a very short time the several firms engaged will have the means of producing at least 300,000 tons of aluminium a year.

However, remembering that aluminium is relatively nearly twice as abundant as iron, and very many times as abundant as copper, lead, zinc, tin, etc. (table, p. 219), as a metallic constituent of the earth's crust, it would appear that the aluminium industry has an exceedingly promising future before it. Given cheaper methods of production, such as the direct smelting of bauxite, and the manufacture of a suitable form or alloy of the metal, together with a properly cultivated demand, it is theoretically capable of development to proportions as great, or exceeding, that of the present iron and steel industry. Compared with the development of the older metals, for example iron, the metallurgy of aluminium is a growth of yesterday. It would have been forgivable if in the primitive stages of the iron industry we had found workers endeavouring to forge cast iron, or utilise wrought iron for making cutting tools.

In the most recent of the authoritative books on aluminium, by R. J. Anderson, the word *refining* does not find a place in the subject index. It was, in view of the easily oxidisable character of molten aluminium, considered inadvisable to try and refine the metal after it was obtained. Every care was taken to insure the purity of the alumina, and of the solvent (cryolite), and the electrodes and furnace lining, and thus obtain an exceedingly pure metal. Recent work by F. C. Frary, of the Aluminium Company of America, has resulted in an electrolytic process by which, it is claimed, actual refining can be carried out. Such a process, if it succeeds in practice, would immediately render available a lower grade of quality in the materials employed in the furnace, *i.e.* the alumina, etc., and this in its turn will probably mean that a lower grade of bauxite than is now insisted on will be available. However, all the interdependent factors are evidently not yet sufficiently established for any immediate revolutionary changes in materials, etc., to be introduced.

# CHAPTER X.

## THE ALUMINIUM INDUSTRY.

**Existing Organisations.**—There are few industries so monopolised by " combines " as that of aluminium. Practically the entire world's production of this metal is controlled by four great companies ; five if we include the State-owned German works. These firms own reduction works in more than one country, and seldom divulge their output and other statistics. In these circumstances it is very difficult to arrive at correct estimates of production. Table, p. 220, although compiled with care, is only approximate, as the figures refer to the works of different companies in a particular country. *The Mineral Industry* endeavours to correct this by recording the output of companies, as seen in table on opposite page, for the aluminium production in 1920 to 1925.

The ramifications of the American, British, French, Swiss, and German firms will become clear if the aluminium industry in each country is dealt with separately.

The following information has been collected from various sources, but chiefly from *The Mineral Industry* and *The Mining Journal.*

**Australia.**—There are no reduction works in Australia. Enquiries are in progress with a view to establishing plant for the treatment of the bauxite of New South Wales, particularly the 4,000,000 tons of ore said to have been proved at Wingello, near Moss Vale, N.S.W. (see *The Mineral Industry* for 1900). There are also bauxite occurrences in Queensland. During the war the Electrolytic Zinc Company announced their intention of establishing an aluminium reduction works, having an annual capacity of 4000 tons of metal, at Hobart, Tasmania.

**Austria.**—As far as information is available, it would appear that there are at least two aluminium reduction works in Austria—one at Lend Gastien, in the Austrian Tyrol of Salzburg, operated by the Aluminium Industrie A.G. of Neuhausen, Switzerland ; the other, the Steeg works, near Goisern, on the shores of Lake Hallstaedt, erected towards the close of the Great War by the Austrian Government. The estimated capacity of the Austrian works is said to be 10,000 tons (roughly). The location of alumina works has not been determined, but as the name Rauris has been frequently mentioned in connection with a reduction plant, it is presumed that this is an alumina works of the Aluminium Industrie A.G. The bauxite occurrences of Austria have been described by R. Helmhacker (see *Eng. and Min. Jour.*, 15 Oct., 1898). There are recent statistics of an output of bauxite from the Salzburg region (see *Zeitsch. fur Prak. Geol.*, Oct., 1921, p. 19; also, *Montanistisch Rundschau*, vol. xiv, 1922, 16 Sept., p. 385, and 1 Dec., p. 464).

| Name. | Output in Metric Tons. | | | | | |
|---|---|---|---|---|---|---|
| | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
| 1. Aluminium Company of America, U.S.A. . . . . . | 87,300 | 28,750 | 52,000 | 101,000 | 93,000 | |
| 2. Northern Aluminium Company of Canada . . . . . | — | 4,000 | 9,000 | 16,500 | 16,000 | |
| 3. British Aluminium Company of Scotland and Norway . . | 10,000 | 8,510 | 11,500 | 12,000 | 10,000 | |
| 4. The Aluminium Corporation, Wales . | 800 | 1,000 | 1,000 | 1,000 | 1,000 | |
| 5. L'Aluminium Française of France and Norway . . . . | 14,000 | 10,000 | 15,000 | 17,000 | 28,500 | |
| 6. Aluminium-Industrie-Aktien-Gesellschaft, Switzerland, Germany and Austria . . . | 15,000 | 15,000 | 16,000 | 17,000 | 23,000 | |
| 7. L'Aluminio Italiano of Italy . . | 1,238 | 740 | 630 | 1,500 | 2,000 | |
| 8. German Government and other works . . . . . . | 15,000 | 12,000 | 12,000 | 13,000 | 12,000 | |
| Total . . . . . | 155,338 | 80,000 | 117,130 | 179,000 | 185,500 | |

**Belgium.**—There are evidently no reduction works in Belgium, and no bauxite is known to occur in that country. The Société de l'Aluminium et ses Dérives at one time purified imported bauxite by the Peniakoff process. This company has since been dissolved.

The Société Filiale Belge-Nederlandaise, also using the Peniakoff process in the preparation of alumina, had works at Selzaete ; they were controlled by L'Aluminium Française. These chemical works were damaged during the war, and, although some other sections of the works have been put in order, the manufacture of alumina has not been recommenced.

**British Guiana.**—Extensive beds of bauxite, notably the Three Friends deposits above Georgetown on the Demerara River, have been proved in this colony. There are several waterfalls capable of furnishing hydro-electric power. Bauxite has been worked by the Demerara Bauxite Company. They suspended operations in 1921, owing to a lack of demand, but the production recently (1924) has been roughly 20,000 tons a month. This company is subsidiary of the Northern Aluminium Company of Canada. It was operated in conjunction with the Merrimac Chemical Company of Boston, Mass., but this association has long since been terminated. A London company is also being formed to exploit the bauxite occurrences along the Demerara River which are not under the control of the Demerara Bauxite Company. An excellent account of the ramifications of the companies operating in British Guiana is given by L. T. Emory, in the *Eng. and Min. Journ. Press* for 25 April, 1925. From the available information, it would appear that a considerable time will elapse before reduction works are likely to be erected in that colony, in spite of the attractiveness of various hydro-electric sites. The Demerara Bauxite Company will ship ore to the United States, and the reduction works in Canada will most likely be enlarged. As regards any development by the London interests, it will certainly be in the direction of exporting bauxite to Scotland for the new reduction works there.

**Canada.**—Although various discoveries of bauxite have been reported from the West, no deposits of value appear to have been found. The Northern Aluminium Company—a subsidiary of the Aluminium Company of America—produces aluminium at Shawinigan Falls, twenty miles north-west of Three Rivers, in Quebec. This plant works in conjunction with fabrication works at Shawinigan and a manufactory in Toronto (Ontario) for producing cooking utensils, etc. The capacity of the above plant (56,000 h.p.) is estimated at 15,000 to 20,000 tons of metal a year. It obtains its calcined alumina from East St. Louis, Illinois, U.S.A. As stated previously, the Northern Aluminium Company of Canada have large interests in the bauxite deposits of British Guiana. It is said that one of the conditions of the lease was that the Aluminium Company of America would either establish reduction works in British Guiana or enlarge the capacity of the Shawinigan Falls plant. They are reported to be developing the latter as well as establishing a new works at Chute a Caron, Quebec.

**Dutch Guiana.**—The Surinaamsche Bauxite Maatschappji, operating 100 miles above Paramaribo on the Surinam River, have established a drying plant and docks at Moenge. The Aluminium Company of America have considerable interests in the above organisation, and thus control certain bauxite deposits in Dutch Guiana. The Norton Company of Worcester, Mass., also appear to have small holdings in this colony.

**East Africa.**—Attention has been drawn to the bauxite deposits of Amani, in East Usambara. Amani lies fifty miles inland from the coastal town of Tanga, on the railway to Moshi. It is not likely that any serious development will take place in this region of the Indian Ocean seaboard for many years to come. These remarks apply also to the bauxite of Nyassaland, to Madagascar, and the Seychelles.

**France.**—It is most difficult to trace the ramifications of the several companies which operate in France. However, in 1911, L'Aluminium Française was established by the energy of the late M. Badin as the selling agency for the following producers of aluminium :—

(1) Compagnie des Produits chimiques d'Alais et de la Camargue of Pechiney, with a capital of 80 million francs. This company operates the works of St. Michel (Calypso) and St. Jean de Maurienne.

(2) Société Électrometallurgique Française of Froges, with a capital of 50 million francs. They control the reduction works at La Praz, near Modane, St. Michel (Felix ?) de Maurienne, and l'Argentière.

(3) Société d'Électrochimie et l'Électro-Metallurgie, with works at Premont and Martigny.

(4) Société des Forces Mortrices de l'Arve, with a factory at Chedde ; and

(5) La Société (de produits Électrolytiques) Électro-Metallurgique des Pyrénées, operating at Auzat.

During the war (1) appears to have absorbed (4) and (5), then (2), and finally amalgamated with (3). Thus it is seen l'Aluminium Française practically controls the entire French output of aluminium. M. Badin also brought into being the Southern Aluminium Company of Whitney, N.C., U.S.A. This concern passed into the control of the Aluminium Company of America early in the war. The great French organiser also established l'Aluminio Italiano of Turin, which is still largely backed by French capital. L'Aluminium Française also controls the output of two important reduction works in Norway.

The aluminium ore (bauxite) for all the French and Norwegian works is obtained from the occurrences in Languedoc and Provence, particularly from mines near Brignoles in the Var, and from the Départements des Bouches du Rhone, Hérault, and the Ariège. The Union des Bauxite of 39 Cour Joseph Thierry, Marseilles, are the local representatives of the British Aluminium Company, Limited.

Alumina is prepared at the following places :—

(1) Gardanne (Bouches du Rhone) ;
(2) Salindras (Gard) and
(3) Saint Auban (Basses Alpes), by the Cie d'Alais Froges et Camargue, etc. ;
(4) La Barasse (Bouches du Rhone), of the Ste. d'Électrochimie et Électro-Metallurgique ;
(5) Arreau, in the Pyrénées, belonging to the Ste. l'Aluminium du Sud-Ouest ;
(6) St. Louis-les-Aygalades, near Marseilles, originally the property of the Aluminium Industrie A.G. of Neuhausen, but now worked by the Cie d'Alais Froges et Camargue, etc. ;
(7) Peynier Rousset (Bouches du Rhone) of the Cie des Bauxite et Alumines de Provence ; and
(8) Menessis (Somme) of the Ste. Française des Produits Aluminiens, but these works were damaged in the war, and are not yet reported working again.

Except for (7), all the above alumina works are under the control of L'Aluminium Française. No alumina works appear to be operating in the regions of Hérault and the Var.

The reduction works are situated as follows : Two, the Auzat works near Viedessos, and the Arreau plant on the Neste, in the Haute Pyrénées, and eight factories in the French Alps. These latter are :—

(1) The Chedde works, on the Arve (Haute Savoie) ;
(2) St. Michel (Calypso), below Vallois in Savoie ;
(3) La Praz, near Modane, on the Arc (Savoie) ;
(4) St. Jean de Maurienne, in the valley of the Arc (Savoie) ;
(5) St. Félix (La Sanssaz), also on the Arc (Savoie) ;
(6) St. Michel (a second) de Maurienne, on the Arc in Savoie ;
(7) Premont (La Shertan ?) in the valley of the Arc ; and
(8) Argentièrre, on the River Durance, in Hautes Alpes.

Other names mentioned in association with reduction works in the Alps region are Froges, Pontamafrey, and Épierre. It is not clear whether these names are intended for the location of any of the above-named works or for other plant. Small works were originally established at Froges in the early days of the Hérault process.

The estimated capacity of the various French works (in France) is probably 25,000 tons of aluminium a year.

**French Guiana.**—The Guiana Development Company are said to have begun work on the bauxite occurrences on the Marowine River.

**Germany.**—Before the war there was only one aluminium reduction factory in Germany. This was the Rheinfelden works of the Aluminium Industrie A.G., near Basle (Baden).

In 1914 the capacity of this plant did not exceed 800 tons of aluminium annually, but by 1918 it had been enlarged to produce 3500 tons a year. Much of the aluminium obtained by Germany during the opening stages of the war came from Switzerland. In addition to the German interests vested in the Aluminium Industrie A.G., there is the firm of Gebrüder Giulini, of Ludwigshafen, who own reduction works at Martigny, in Canton Vaud (Switzerland), alumina plant at Ludwigshafen, and rolling mills at Wutöschingen (Baden). Krupps were said to be contemplating the erection of reduction works in Silesia during the war.

In 1915 temporary reduction works (for the war) were erected at Rummelsburg, near Berlin, by the collaboration of the Metallbank and Metallurgische Gesellschaft of Frankfurt-am-Main and the Chemische Fabrik Griesheim Elektron. The following were also established in 1915 :—

(1) The Vereinigte Aluminium Works A.G. ;[1]
(2) The Erftwerke A.G. ; and
(3) The Innwerke Bayerische Aluminium A.G.

*The Vereingte Aluminium Works* were formed by the Griesheim Elektron Company and the Metallbank, with a capital of 50 million *marks*. They erected reduction works at Horrem (3500 tons capacity), near Cologne and Bitterfeld (3500 tons capacity), also in the vicinity of Cologne, in an incredibly short time, and began the construction of the Lautewerke (14,000 tons capacity) at Lausitz, near Hoyerswerda, in 1917.

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[1] "*Vereinigte Aluminium Werke A.G.*—The above company, which controls, either directly or indirectly, the German aluminium industry, has issued its report covering the year 1925. The gross profit for the year was 7,510,000 marks, compared with 6,410,000 marks for 1924, and the net profit, after deduction of trading costs, interest, and making a liberal allowance for depreciation and amortisation, amounted to 3,930,000 marks, which compares with 3,570,000 marks for 1924. According to the report, the business up to May, 1925, was good, but after that date the effect of the general economic depression in Germany made itself felt in the form of diminished inquiry for aluminium and a decline in its price. In consequence of this, the net result of the year's operations is not much greater than in 1924, although for the latter part of the year the Innwerke plant was producing aluminium. Chiefly due to this latter fact, the production of aluminium for the year amounted to 19,400 tons, against 11,800 tons in 1924. Inland sales have been below expectations. The Erftwerke company, which is a subsidiary of the Vereinigte Aluminium Werke, has limited its output of aluminium, due to the smaller inland demand, but in consequence of the business done in the electrode manufacturing branch of this company, it has been able to distribute a dividend of 5 per cent. for 1925.

"The bauxite mines in which the Vereinigte Aluminium Company is interested have been further explored, and at present have about ten years' ore in sight. During the year, in consequence of difficulties experienced with the Italian Government regarding bauxite supplies from Istria, the company has decided to acquire interests in Rumanian and Hungarian bauxite mines."

[*The Mining Journal*, 24 April, 1926.

*The Erftwerke A.G.* were floated by Gebrüder Giulini in conjunction with the Rheinisch-Westfälischer Electricitätswerk, with a capital of 15 million *marks*. They established a large reduction plant (14,000 tons capacity) at Grevenbroich, on the Erft (a tributary of the Rhine). An electrode factory was also erected in conjunction with these works. The above aluminium works were designed only to meet the emergencies of a war demand. The cost of production is high, and the first three works have since been closed. They obtain the necessary electric energy by using lignite fuel in a power plant in the vicinity of Knap-Sack, near Cologne, and Reisholz, near Düsseldorf. Both the above companies have worked together as a syndicate—the Vereinigte Aluminium-werke Laute—with State assistance. The sales organisation of these works is controlled by the Metallgesellschaft of Frankfurt-am-Main.

*The Innwerk Bayerische Aluminium A.G.*, with a capital of 13 millions *marks*, was brought into being by the joint efforts of the Allgemeine Electricitäts A.G. (A.E.G.) and the Siemens Schuckert Companies, erecting reduction works (to produce 10,000 tons of aluminium annually) on the Inn, near Mühldorf (Bavaria); it will obtain the necessary electric energy from a hydro-electric power site in the Alps.

All these German reduction works are, or will be, supplied with pure alumina from one or other of the following purification plants:—

(*a*) Curtius, Duisburg;
(*b*) Giuliniwerke, at Mundenheim, near (?) Ludwigshafen (capacity 60 tons of alumina a day);
(*c*) Martinswerke, Neuhausen (capacity, 130 tons of alumina a day); and
(*d*) Hassenclaeveawerke, Honningen, near Coblenz (capacity, 35 tons of alumina a day).

The Griesheim interests are also reported to have alumina works in Silesia, while the Aluminium Industrie A.G. are said to have established alumina works at Bergheim, west of Cologne.

The German alumina works were supplied, during the war, with bauxite from various sources, chiefly from: Siebenbergen (Siegengürgen), in the Bihar region of Transylvania; the Adriatic islands and littoral of Dalmatia and Istria; the mines in S. Croatia; near Untersburg, in Salzburg (Austria); and from domestic supplies in Hesse. Since the war the domestic bauxite occurrences have received considerable attention. Mines have been opened near Frankfurt in the Darmstadt area of Ober Hesse, and on the western slopes of the Vogelsburg. The chief home producers have amalgamated as the Bauxitwerk A.G. of Frankfurt-am-Main, and this organisation effects its sales through the Vereinigung Hessischer Bauxitgruben G.m.b.h. of Munster.

The aluminium reduction works at Rummelsburg, Horrem, and Bitterfeld have, as already stated, been closed down. The Lauta and Grevenbroich plants continue in operation, although the Lauta works have not been developed to their full capacity. It is reported that the late Herr Stinnes owned a large interest in the Erftwerke (Grevenbroich plant), but sold out to the Government owing to the difficulties the German works experienced in obtaining regular supplies of bauxite. From the above data it would appear that the German works at present operating have an annual producing capacity of about 20,000 tons of aluminium. When the Innwerke plant is completed, and the Lauta-werke brought to its designed capacity, the German output will be capable of attaining 38,000 tons of metal a year. By reopening the factories already closed down and working at full load, it is estimated that the total production could be increased to 60,000 tons or more of aluminium a year. Practically the whole aluminium industry of Germany is owned by the State, but operated on business lines.

**Gold Coast.**—Deposits of bauxite have been located at Mount Ejuanema, on the Kwahu plateau, near Mpraeso. The nearest railway station is Tafo, forty miles away, but a line to Coomassie will pass within two miles of the occurrence. The question of development is still under consideration.

**Great Britain.**—The British Aluminium Company, Limited, of Adelaide House, King William Street, London, controls practically the entire aluminium production of the United Kingdom. They operate bauxite mines in the south of France: in the Var, in Hérault, and the Ariège. Their local representatives in Marseilles are the Union des Bauxites (lately of Montpellier). The raw material is shipped to the Company's alumina works at Larne Harbour, co. Antrim, Ireland (see paper by J. Sutherland in *Engineering*, vol. 62, 1896, pp. 291-292), and to their new plant at Burntisland, Fifeshire, Scotland. The alumina from these factories supplies their reduction works in Scotland and Norway. The Scotch works are located at Kinlochleven, in Argyllshire, and Foyers, in Inverness-shire. There is an elaborate electrode factory at Kinlochleven. The present capacity of the Scotch reduction works is estimated at 12,000 tons of aluminium a year, but when the sanctioned Lochaber scheme has been completed, the productive capacity will probably be increased to 20,000 tons a year.

The British Aluminium Company have rolling mills, etc., at Warrington, in Lancashire, and at Milton, in Staffordshire, which operate in conjunction with their reduction works for the preparation of finished metal, such as sheets, circles, tubes, wire, etc.

In addition to the above-mentioned establishments, this company has an electrode factory and two reduction works, one at Vigelands and the other at Stangfjord, in Norway. They have offices at 165 Broadway, New York, and 592 King Street, W., Toronto, and have representatives in India and other countries.

It is not clear that the British Aluminium Company intend to carry out their hydro-electric project at Orsières, in Switzerland, with a view to establishing reduction works in that vicinity. It is not to be forgotten that this company has interests in the bauxite deposits of British Guiana, and is likely to examine other deposits if the transport facilities are attractive.

The only other aluminium producing company in Great Britain is the Aluminium Corporation, Limited. During the war they operated some bauxite mines in the south of France (Sillans, Var), purified the raw material in their alumina works at Hebburn, near Newcastle-on-Tyne, and reduced the alumina to aluminium at Dolgarrog, near Conway, in North Wales. The output capacity of the Dolgarrog works before the collapse of their dam in 1925 is said to have been from 1000 to 1500 tons of aluminium a year.

**Hungary (see Rumania).**—Bauxite occurrences had been located in the Bihar region of Transylvania before the war. No developments appear to have taken place till 1915, when, as a result of an urgent German demand, several companies were formed and mining operations were begun on an ambitious scale. One company, which was floated at Budapest with a capital—chiefly from German sources—of 9 million kronen, had in view the establishment of alumina and aluminium reduction works near the mines.

However, the controlling firm was undoubtedly the Graf Kosniss Trust, represented chiefly by (1) the Jadtal Aluminium Mining Company, with its workings at Baratka, Elesd, Kalota, and Jadremete ; and (2) the Vaskoner Iron and Aluminium Mining Company, with its mines near Rev and Bihardobrosd. Since this territory has been ceded to Rumania, a report has been current that a reduction plant to treat alunite (?) is nearing completion at Bereg. It is also reported that bauxite has been discovered in the Bakony district, near the railroad between Veszprem and Deveczer, and this occurrence is to be developed by the Talpolcaer Mining Company of Budapest (see *The Mining Journal*, vol. 133, 1921, p. 326).

**India.**—The Indian production of bauxite in 1924 exceeded 20,000 tons (see table on p. 255). This is the highest output on record. At present Indian bauxite is only used for chemical purposes and for the purification of petroleum, but numerous enquiries are being made and a considerable development is shortly expected. Imported aluminium ingots are manufactured into various types of aluminium goods at certain centres in the Madras Presidency and other places in India.

Although occurrences of high-grade bauxite have been found in many localities in India—for example, Western Chota Nagpur, Jabalpur, Balaghat, Kolhapur, Belgaum, Kashmir, etc., no alumina works or reduction plant have so far been erected. Schemes have repeatedly been put forward, but owing to the small demand for aluminium it is thought that the time is not quite ripe for the production of aluminium in India.

Attempts are being made to work the Kashmir (Jammu) bauxite at Chakar, where a small coalfield exists, and in the vicinity of which there is a suitable site for a hydro-electric installation. However, the peculiar character (diaspore) of the ore is an important factor. It has been found to be relatively insoluble and does not lend itself to treatment by the usual processes employed for the purification of bauxite.

Messrs. Tata & Company, Limited, also have a project in view for the establishment of a large hydro-electric installation (known as the Koyna Valley hydro-electric scheme) on the Western Ghats of the Bombay Presidency. The same company have in mind the erection of alumina and aluminium reduction works on the Jaigad peninsula in connection with their Electro-Chemicals Company. The underlying factors in the scheme are the disposal of the electrical energy from the Koyna scheme to Jaigad, the use of bauxite from Belgaum, and the manufacture of aluminium. However, matters have not passed the investigation stage.

Another large hydro-electric project which has been mentioned in connection with the reduction of alumina is that of the Sutlej River scheme in the Punjab due west of Simla. This scheme has been under consideration for some time. It has been estimated that 300,000 e.h.p. can be obtained if the full resources of the Sutlej River at Malouna bend above the Bhakhra gorge are developed. In the event of the scheme being sanctioned it is possible that alumina made at Katni, in the Central Provinces, could be profitably reduced to aluminium in the vicinity of Amballa. Several schemes are being considered in which cheap fuel—coal—will be employed for power generation. The most attractive of these are those of the Damuda valley about Karanpura, using bauxite from Lohardaga ; Umaria in Rewa using bauxite from Katin ; Bilaspur using Korba coal and bauxite from Armakantak. In no case do I think can power be got at less than 75 annas a kilowatt-hour from Indian coal, except, perhaps, in association with a coke oven plant.

**Italy.**—The first producer of aluminium in Italy was the Società Italiano per la Fabricazione del l'Aluminio of Bussi (Aquila). This company obtains bauxite from the Abruzzi occurrences, and purifies it to alumina at Bussi. In addition to an elaborate electrode factory which works in conjunction with the Bussi reduction works, there is also a chemical works for the manufacture of aluminium sulphate at Bussi. According to a recent report (James M. Hill, 1923) the above company has been absorbed by the Società Italiana di Elettrochimica).

There are other interests, for example, the L'Aluminio Italiano, which was established by the late M. Badin, of the L'Aluminium Française. The capital of L'Aluminio Italiano is said to be 20 million lire, and the company is composed of the following firms :—

(1) Società idro-electrica de Villeneuve et Borgofranco with twenty shares.
(2) Società des Tresfilières du Havre with forty shares.
(3) Società Traviliere at Lamanitoi di Metalli, with forty shares.

L'Aluminio Italiano have erected large reduction works at Villeneuve, in the Val d'Aosta, the necessary power being obtained from a hydro-electric plant near Borgofranco. This company works the valuable bauxite deposits in the Lecci dei Marsi (Tamnium) area, and also obtains supplies from the occurrences of high-grade bauxite in Istria.

It is anticipated that the Bussi Company will amalgamate with L'Aluminio Italiano, and that both companies may become State subsidiaries.

The total capacity of the existing Italian aluminium works is estimated to be about 5000 tons of virgin metal a year.

**Japan.**—No bauxite has hitherto been discovered in Japan, Korea, or Taiwan (Formosa). Experiments with high alumina clays have been made, but no satisfactory process for the preparation of alumina from such material has yet been devised. An American-Japanese syndicate with a capital equally subscribed of $5,000,000 is said to have been formed with a view to importing bauxite, possibly from India ; erecting alumina works in the vicinity of the coal mines of Kinshu (South Japan) ; and establishing aluminium reduction works at Fushiki Harbour, Toyama. The syndicate contemplate obtaining the requisite electrical energy for the reduction works from a hydro-electric station on the Jintsu River. The Aluminium Company of America have established a selling agency in Tokio. This firm is known as the Asiatic Aluminium Company, and is said to have an authorised capital of 100,000 yen. An aluminium reduction works is reported in process of erection at Kachigawa, near Nagoya (Yoyogi ?).

**Yugo-Slavia** (Croatia, Dalmatia, Istria, and islands off these coasts).—Bauxite has been worked in a number of places in the areas named above ; for example, some of the bauxites of the

Kerka River, the hills of Zagorge, the Dalmatian Islands, Rammaljane in the Mosec plains, and localities in the vicinity of Blaca and Konjsko, north of Clissa, and at Kalun.

Over thirty companies were said to have been operating during the war. The more important of these are :—

(1) Bauxit-Aktien-Gesellschaft of Budapest, with its mines in the islands of Veglia, Arbe, Goli, and S. Gregoria, as well as at Obrovazzo and Dernis ;

(2) Montani Bergbau Gesellschaft of Vienna (present headquarters are in Trieste), which works some of the mines of Monte Kalun ;

(3) Bernado Wetzler & Company, of Fiume, with properties at Chermenizza and Ripenda ;

(4) Erzwertung Gesellschaft of Sasak, with workings in the islands of Arbe, Cherso, and Pago, and on the mainland near Dernis ;

(5) Aluminiumerz Bergbau und Industrie A.-Gr. of Vienna. This company has since been reconstructed at Fiume under another name. They operate on the island of Cherso ;

(6) Arsa Company of Trieste (originally Trifailerkohlenwerke A.-G. of Vienna) ; and

(7) A Franco-American Syndicate, together with several other small companies.

Many of the above mines were worked under the control of the late Austro-Hungarian Government. War prices appear to have been based on the amount of *available alumina* (A), in accordance with the formula, A = total alumina — twice percentage of silica. First quality bauxite was said to be 44 per cent. alumina on this calculation.

Considerable exports of bauxite from Serbenico have been made since the war (see table on p. 258).

Since the war operations are said to be on foot for the erection of an aluminium reduction works at Plivitz for the production of metal from the bauxite of Bruvno, near Rudopolje, in the Lika district.

**Norway.**—The Aktieselskabet Vigelands Brug at Vennesla, near Christiansand, sold out to the British Aluminium Company about twelve years ago. The factories at Vigelands and Stangfjord have subsequently been developed by the British Aluminium Company, until they are now capable of an output of 4000 to 5000 tons of aluminium a year. It is believed that an electrode factory has been established at the Stangfjord works.

L'Aluminium Française have a controlling interest in the Societa Norvegienne des Nitriures (Det Norsk Nitrid Company), which is a branch of the Compagnie des produits chimique d'Alais. The

Norwegian company have two reduction works—one, a 20,000 h.p. plant with a capacity of 4000 tons of metal a year, at Eydhaven, near Arendal; and the other, a 30,000 h.p. plant, with a capacity of 6000 tons of aluminium per annum, at Tyssedal, near Odde, on the Hardangerfjord. There is an electrode factory at the Arendale works. These factories appear to be worked in conjunction with a nitrogen fixation plant which utilises the Serpek process and produces pure alumina as a by-product.

Purely Norwegian interests were, till recently, represented by the Société Norvegienne de Hoyangfaldene (known as the Norsk Aluminium Company), at Hoyang, on the Sognefjord. Their works have an available power equal to 60,000 kw., and are designed for an output of nearly 7000 tons of aluminium in addition to 5000 tons of carbon electrodes, and 12,000 tons of calcium carbide. Unlike the British and French controlled works, which work their own bauxite concessions in France, and prepare their own alumina, this company has always found it difficult to obtain a sure and regular supply of alumina. So great has been their difficulty, that they experimented at Nidaros-Teglverk, near Tronghjem, with a process for extracting alumina from clay, and were interested in a Goldschmidt method of obtaining alumina from the extensive domestic occurrences of labradorite felspar. Although the experiments are said to have been successful, a commercial application has not yet emerged. In fact, till quite recently the Norsk Aluminium Company were negotiating for imports of bauxite from Dutch Guiana. Their difficulties appear to have led to financial entanglements. These embarrassments, however, have been solved by an understanding with the Aluminium Company of America, who, for a loan of upwards of 7,000,000 kronen, have obtained control of the Norsk plant. It is thus seen that the British, French, and American groups are now represented in Norway.

The total capacity of the various reduction works in Norway is estimated at 20,000 tons of aluminium a year. Further expansion is anticipated in view of the cheap electrical energy which will be available in the hydro-electrical installations now projected in Norway (see *Engineering*, vol. 106, 1918, pp. 163-165; 1919-23, pp. 218-220).

**Rumania.**—The bauxite occurrences of the Bihar region in Transylvania (ceded to Rumania since the war) have already been briefly discussed under Hungary. Although these bauxite reserves are estimated at 20,000,000 tons, they occur in very difficult country.

During the war the deposits were worked at several places but at present their exploitation is in the hands of only two firms—the Alumina Company and the Bauxita Company—who are exporting the mineral to Germany and Switzerland.

Permission for exportation has been given on condition that in course of time the two companies named establish the manufacture of aluminium in the country itself on a sufficiently large scale to supply its requirements (see *The Mining Journal* for 25 November, 1922).

**Russia.**—Bauxite is reported to have been discovered on the banks of the Wolozoba River, 30 miles south-east of Tischwin, in the Novgorod district, as early as 1882. Some development work appears to have been done during the war, but no particulars are to hand. There are evidently no reduction works yet operating in Russia.

**Sierra Leone.**—Bauxite has recently (1921) been reported from near Falaba by the Geological Survey of Sierra Leone. It is said to average $Al_2O_3$, 51·08 per cent.; $Fe_2O_3$, 14·41 per cent.; $SiO_2$, 9·46 per cent.; and loss chiefly $H_2O$, 25·32 per cent. No estimates of quantity are stated.

**Spain.**—The poor quality bauxite from Catalonia, in the Spanish Pyrenees, attracted attention twenty years ago (1902), when a Franco-Spanish syndicate was formed with a view to erecting reduction works at Zudauic. The factory never seems to have been established, and Spanish bauxite is only used in a small way at present.

**Switzerland.**—The Aluminium-Industrie-Aktien-Gesellschaft of Neuhausen, which is largely backed by German capital, has aluminium reduction works at Neuhausen, near Schaffhausen; at Rheinfelden, above Basle, in Baden (Germany); at Chippis (Borgne) at the confluence of the Rhone and Navisance, in Canton Valais (Switzerland); and at Lend Gestein and Rauris (?), in the Austrian Tyrol. An alumina works at Bergheim, near Cologne, is said to belong to this company, but it is not clear if this name is being confused with one or other of the works of the Lauta syndicate. It is not certain from what sources they obtain their bauxite and alumina. Their St. Louis-les-Aygalades alumina factory, near Marseilles, is now operated by L'Aluminium Française. It is thought that this long-established company obtain their supplies of raw material, etc., from the same sources as those of the works of the Vereinigte-Lauta syndicate already discussed. There is an alumina plant at Bergheim, west of Cologne, which belongs to the A.I.A.G., and another at Neuhausen (?), which belongs to the Lauta combine.

Another firm of importance is that of Gebrüder Giulini G.m.b.H. of Ludwigshafen, on the Rhine. They have alumina works at Ludwigshafen, a reduction plant at Martigny, in Canton Vaud, and a rolling mills, etc., at Wutöschingen, in Baden. Gebrüder Giulini is reported to have recently been reorganised as the Aluminium Fabrik-Martigny A.G.

The estimated annual production of aluminium from reduction works situated actually in Switzerland, *i.e.* about four works, is approximately 15,000 to 20,000 tons.

The war contract of the German Government for aluminium from the Aluminium-Industrie-Aktien-Gesellschaft of Neuhausen was finally cancelled by a payment of 11 million Swiss francs to this company.

**U.S.A.**—The Aluminium Company of America, Pittsburg, Pa., under Mr. A. V. Davis, and supported by the Mellon banking interests, practically controls the entire aluminium industry in the U.S.A. and Canada.

> "It controls the mining of bauxite, the reduction of aluminium, the fabrication of sand castings—the last through its subsidiary, the Aluminium Manufacturers, Inc." (See *The Mineral Industry* for 1921, p. 15.)

The present estimated capacity of the reduction works under the control of this organisation is, roughly, 100,000 tons of aluminium a year. Operations are in progress by the Cheoah Aluminium Company of Tennessee, a subsidiary of the Aluminium Company of America, at a power site on the Little Tennessee River, in the Great Smoky Mountains south of Knoxville, by which it is hoped to obtain enough electrical energy for the Alcoa (Maryville) reduction works, so as to enable it to produce 80,000 tons of metal a year, and thus double the present U.S.A. output.

The existing reduction works operating under the auspices of the Aluminium Company of America are :—

(1) The Shawinigan Falls plant (20,000 tons), including the fabrication works at Shawinigan and Toronto, have already been discussed under "Canada."

(2) Two reduction works at Niagara Falls, N.Y., with a capacity of 25,000 to 30,000 tons of aluminium a year.

The manufacturing arm of the above works is represented by the United States Aluminium Company with its factory and research laboratory at New Kensington, Pa. There is a fabricating works at Edgewater, New Jersey.

(3) The Massena Springs plant in St. Lawrence Co., N.Y., which is supplied with power (100,000 h.p.) from Cedar Rapids, 45 miles to the north-east. The capacity of these works is computed at 30,000 tons of metal per annum on full load. There is also a fabrication plant working in conjunction at Massena, N.Y.

(4) The Badin works (50,000 h.p.) of the Southern Aluminium Company, situated at Whitney, N.C. This plant was designed and erected by the late M. Badin, of L'Aluminium Française. It was, however, taken over before completion,

in 1915, by Mr. A. V. Davis, on behalf of the Aluminium Company of America. The estimated capacity of this plant as erected is said to be over 20,000 tons of virgin metal a year.

(5) Maryville (Alcoa plant), Tenn. As already stated, this plant is to be enormously enlarged. It is hoped that the Knoxville power scheme will be in working order by 1925. The Maryville plant will then have a full-load output equal to the present production of the reduction works now operating in the States, *i.e.* roughly, 80,000 tons of metal per annum. Rolling mills to deal with part of the contemplated output of the Maryville works have been erected at Alcoa, Tenn., and other manufacturing works are in process of construction on the Hudson River, at Edgewater, N.J.

The Aluminium Company of America have recently obtained control of the works of the Norsk Aluminium Company of Hoyan, Sognefjord, Norway (see *The Mining Journal* for 25 Nov., 1922).

The supply of alumina for the above-mentioned American works is obtained from one or other of the following alumina works :—

(*a*) East St. Louis, Illinois.—This plant treats bauxite from the Arkansas field, and supplies the reduction works at Niagara Falls, Massena Springs, and Shawinigan Falls. It appears to be the only alumina works operated by the Aluminium Company of America which is actively engaged.

(*b*) Sollers Point, Baltimore, Ind.—The Aluminium Ore Company of Baltimore are said to have erected alumina works at the above site, near Sparrow's Point, to deal with imported bauxite (from British Guiana, in agreement with the Demerara Bauxite Company).

(*c*) Tennessee.—It has not been possible to locate the position of any alumina works in this State, but there have been rumours that one exists, or is to be erected, for the supply of alumina to the important Alcoa (Maryville) reduction works.

Carbon electrodes are made at several places—East St. Louis, Ill., New Kensington, Pa., Niagara Falls, N.Y., etc.

The chief bauxite producers are :—

(*a*) The American Bauxite Company, of 1111, Harrison Building, Philadelphia, Pa., who operate in Saline Co., Arkansas, and near Chattanooga, in Tennessee.

(*b*) The Globe Bauxite Company, of Joliek, Illinois, work at Chemical Spur, Arkansas.

(*c*) The Republique Mining and Manufacturing Company, 1111, Harrison Building, Philadelphia, Pa., who have mines at Little Rock in Pulaski Co., Arkansas, near Rome, in

Floyd Co., Georgia, and at Rock Run, in Cherokee Co., Alabama.

(*d*) The Kalbfleisch Bauxite Corporation of 31 Union Square West, New York, N.Y., operate in Bartow and Randolph Co.'s, Georgia, and at East Chattanooga, Tennessee.

(*e*) The Warner Mining Company of Adairsville, Georgia, with mines in Bartow Co., Georgia.

(*f*) The E.I. du Pont de Nemours & Co., of Wilmington, Del., with mines near Little Rock, Arkansas.

(*g*) The Norton Company of Worcester, Mass., with interests in Saline and Pulaski Co.'s, Arkansas ; and others such as the National Bauxite Company of Arkansas and Tennessee ; the Watanga Mining Company of Tennessee ; the Dixie Bauxite Company ; the Consolidated Mining Company of Delkab Co., Alabama ; etc.

Practically all the Arkansas bauxite is used, after purification, for reduction to aluminium ; whereas most of the Georgia bauxite is employed in the chemical industries, the U.S.A. production of bauxite being used as follows :—

| Industry. | Tons of Bauxite. | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1919. | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
| Aluminium | 272,270 | 383,154 | 91,700 | 211,550 | 380,520 | 225,780 | 173,040 |
| Chemical . | 67,842 | 85,878 | 41,000 | 78,550 | 68,870 | 54,870 | 67,420 |
| Abrasive . | 35,395 | 52,276 | 6,850 | 19,500 | 73,300 | 66,920 | 73,980 |
| Refractory | 1,159 | | | | | | |
| Cement . | — | — | — | — | — | | |

It is interesting to record that Georgia bauxite was washed in log washers as long ago as 1899 (the Dixie Bauxite Company), and that similar ore was calcined in the same year (Rep. Min. and Manuf. Co., at Hermitage, Ga.). Recently a process (the Everhart) has been devised for concentrating low-grade bauxite in U.S.A. Further particulars regarding bauxite are given in Part II., Article on "Mining, etc."

The Aluminium Company of America has considerable interests in the bauxite occurrences of British and Dutch Guiana through the Northern Aluminium Company of Canada.

There have been frequent rumours of a determination by other companies, outside the American "ring,"[1] to produce aluminium—

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[1] "The ramifications of the Aluminium Company of America are well shown by its owned and affiliated concerns. It either owns entirely or controls the following :—

notably the Anaconda Copper Mining Company, at their Great Falls works in Montana; the Aluminium Company, of Nitro, West Virginia; and a projected works on the Klamath River by a San Francisco Company. Henry Ford has been endeavouring to obtain the Muscle Shoals nitride plant from the War Department for the purpose of converting it into a works for the production of aluminium, but his bid appears not to have proved sufficiently attractive.

**Venezuela.**—The bauxites of Guiana are known to extend into the territory of Venezuela, but little else yet has been made public.

"(1) *Bauxite Mining Concerns.*—American Bauxite Co., Republic Mining & Manufacturing Co., Demerara Bauxite Co., Bauxites du Midi, Surinaamsche Bauxite Maatschappij, Jadranski Bauxit Dionico Drustov. (2) *Carbon Electrodes.*—Electric Carbon Co. (3) *Alumina.*—Aluminium Ore Co. (4) *Aluminium Reduction.*—Aluminium Co. of America, Northern Aluminium Co., Ltd., Norsk Aluminium Co., new holdings in Canada and holdings in Germany. (5) *Aluminium Alloy Founders and Aluminium Fabricators.*—United States Aluminium Co.; Aluminium Manufactures, Inc.; Northern Aluminium Co., Ltd.; Aluminium Goods Manufacturing Co.; Aluminium Die Casting Corporation; Aluminium Screw Machine Products Co.; Aluminium Seal Co.; and American Body Co. (6) *Selling Agencies.*—Aluminium Cooking Utensil Co.; Aluminium Co. of South America; Northern Aluminium Co., Ltd.; Asia Aluminium Co.; L'Aluminium d'Amérique; Sprostons, Ltd.; and Pierson Roeding & Co. (7) *Railroads.*—Bauxite & Northern Railway Co.; Alton & Southern Railroad Co.; St. Louis & Ohio River Railroad Co.; and Massena Terminal Railroad Co. (8) *Power and Public Utilities Companies.*—Tallassee Power Co.; Knoxville Power Co.; St. Lawrence Securities Co.; St. Lawrence River Power Co.; St. Lawrence Transmission Co.; Massena Electric Light & Power Co.; Hannawa Falls Water Power Co.; Potsdam Electric Light & Power Co.; Ogdensburg Gas Co.; Ogdensburg Power & Light Co.; St. Lawrence Water Co.; Ogdensburg Street Railway Co.; Michigan Gas & Power Co.; Middle West Utilities Co.; Montreal Light, Heat & Power Co.; Cedar Rapids Transmission Co., Ltd.; and the new Canadian holdings with the Duke-Price interests on the Saguenay River and elsewhere. (9) *Miscellaneous.*—Chemical Foundation, Inc.; American Investigation Corp.; Union Trust Co.; Mellon National Bank; American Tar Products Co.; Koppers Co.; Manufacturers & Employees' Mortgage Corporation; Mountain View Development Co.; Frontier Corporation; Pine Grove Realty Co.; Canada Iron Foundries, Ltd.; Perfection Bake Shoppe, Inc.; Seymour House Corp.; Ogdensburg Paper Mills; and others too numerous to mention."

[*The Mining Journal*, 27 February, 1926.

# CHAPTER XI.

## STATISTICAL INFORMATION.

### 1. BAUXITE RESOURCES.

### AFRICA.

**Gold Coast.**—A. E. Kitson has estimated, roughly, 50 million tons of good quality bauxite in the Ejuanema occurrences. The reserves of the Mt. Supirri tract have not yet been ascertained.

**Nyassaland.**—F. Dixey estimates workable ore in the principal occurrence, the Lichenya Plateau, as being of the order of 20 million tons.

**Tanganyika Territory.**—The bauxite occurrences of Amani, etc., have not yet been fully prospected, and no estimates as regards quantity of bauxite have yet been published.

### AMERICA.

**Alabama.**—The bauxite resources of Alabama are not large, but no estimates are available to indicate the actual quantity of ore which remains to be won.

**Arkansas.**—The bauxite occurrences of Little Rock and Bauxite are the largest in the U.S.A., and are said to have yielded over 10 million tons so far, but the present reserves of ore are probably less than this amount.

**Georgia.**—The bauxite deposits of Georgia appear to be second in importance to those of Arkansas; however, estimates as regards quantity are not evidently available.

**Tennessee.**—The bauxite deposits of the Chattanooga district, although valuable, are relatively small.

**British Guiana.**—The most extensive occurrences of bauxite are those of Three Friends and Akyma, but no estimates as regards quantity appear to have been made public by the Demerara Bauxite Company.

**Dutch Guiana.**—The Surinaamsche Bauxite Maatschappij, according to L. T. Emory, possess 95 per cent. of the ore in this colony, chiefly at Moengo Hill, but they have not divulged their estimates. The reserves are thought to be large.

**French Guiana.**—No estimates are available, nor have any been made owing to the need for further prospecting in the areas where workable ore has been found.

**Brazil.**—There are as yet no records of any discovery of workable deposits of bauxite.

## Asia (India).

**Bihar and Orissa.**—The occurrences of Salgi Pat, Dudmatia Pat, Dudha Pat, Serendag, and Kutcha Pat contain upwards of a million tons of rich grey pisolitic bauxite.

**Central Provinces.**—The several deposits south of Katni, in the Jabalpur district, probably contain upwards of 15 million tons of good quality and easily worked bauxite.

The reserves of the Balaghat district are estimated at less than 5 million tons of good bauxite.

No estimates have been made for the Mandla and Seoni districts, while small occurrences are also known to occur in the Bilaspur district and on the Main Pat of Sirguja.

**Central India.**—Small quantities of good bauxite have been located in Rewa State on the Amarkantak plateau by Dr. L. L. Fermor, K. P. Sinor, and myself. E. O. Murray has found bauxite near Mamuni in Kotah. S. M. Mehta discusses the small occurrences of bauxite in Gwalior. The total of many localities is less than 200,000 tons.

**Himalayan Region.**—C. S. Middlemiss has estimated the proved reserves of Jammu bauxite at a million tons.

**Bombay Presidency.**—The bauxite occurrences of Belgaum are computed at 3 to 5 million tons of fairly good quality ore. The occurrences in the Kolhapur district are probably no less, especially since the discovery of Radhanagri by C. S. Fox and Dhangarvadi by H. C. Jones. In addition, Fox has located a moderately fair quality bauxite near Harnai, in the Ratnagiri district. Hallowes has noted bauxite near Bombay. Messrs. Killick Nixon have for some years worked bauxite in Khaira State at Kapadvanj. Recently bauxite is said to have been discovered in Kathiawar.

## Australia.

**New South Wales.**—The amount of accessible bauxite in the Wingello district has been computed at a million tons.

**Queensland.**—No estimates are available.

**West Australia.**—No estimates are available.

## EUROPE.

**France.**—The production of bauxite from the south of France, chiefly from the Var, Bouches-du-Rhone, and Hérault, have probably totalled over 8 million tons. There are still large reserves of good quality red bauxite, but as a general rule, the cost of mining is getting larger and larger annually. It is not possible to estimate the reserves accurately, but it is certain that workable ore to the extent of at least 10 million tons exists.

**Italy.**—No detailed estimates appear to have been made with regard to the bauxite deposits of Aquila, but it is thought the reserves exceed a million tons. The ore from Istria and part of Carniola is said to be attractive in both quantity and quality.

**Yugo-Slavia.**—The bauxite deposits of Dalmatia, Croatia, and part of Carniola occur in irregular lenses in so complicated a manner that no reliable estimate of quantity is possible.

**Austria.**—The bauxite deposits of South Austria in Carinthia and Styria are said to be small, but valuable.

**Hungary.**—Bauxite is said to have been discovered in the Bakony region, near Lake Balaton, but no estimates as regards quality and quantity are yet to hand.

**Rumania.**—O. Pauls has estimated the bauxite reserves of the Bihargebirge region as follows :—

| | |
|---|---|
| Kiralyerdo Plateau . | 12 million tons. |
| Remecz and other areas | ½ ,, ,, |

It is very likely that 20 million tons of ore of fair quality is available from the Kiralyerdo Plateau and elsewhere in Rumania.

**Russia.**—No definite information regarding the quality and quantity of the various reported discoveries of bauxite in Russia are yet to hand.

**Greece.**—No detailed particulars available.

**Spain.**—Small deposits of bauxite of relatively fair grade have been found in Catalonia area, but no estimate as regards quantity have yet appeared.

**Germany.**—The bauxites of the Vogelsberg in Hesse do not find a ready market owing to the poor (siliceous) quality of the ore. The reserves of ore are not large, but no data are to hand as to the estimated quantity.

**Ireland.**—The bauxite of Antrim are not now being used for the preparation of alumina for subsequent reduction to aluminium. The reserves of bauxite must be large, and will probably be valuable to the chemical industry.

## 2. Bauxite Production.

(In Long Tons.) (*Imp. Min. Res. Bureau.*)

| | 1913. | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|---|
| 1. Austria (Styria) | — | 356 | 2,596 | 4,029 | 2,690 | 3,000 | — |
| 2. British Guiana | — | 22,084 | 19,694 | — | 133,562 | 185,091 | 194,339 |
| 3. Dutch Guiana | — | — | — | 12,837 | 12,413 | ‡59,077 | ‡84,150 |
| 4. France | 304,323 | 262,429 | 93,785 | 136,939 | 387,408 | 330,189 | 400,000 |
| 5. Germany | — | 13,200 | ? | 20,500 | 6,547 | 3,035 | — |
| 6. Gold Coast | — | — | — | — | — | — | — |
| 7. Hungary | 1,760* | — | — | — | — | — | — |
| 8. India | 1,184 | 3,931 | 7,584 | 4,919 | 6,547 | 23,228 | — |
| 9. Italy (with Carniola and Istria) | †6,255 | ‡12,928 | 48,330 | 65,396 | 96,479 | 138,527 | 195,000 |
| 10. Yugo-Slavia (Dalmatia-Croatia) | — | §27,000 | 9,860 | 30,787 | 32,000 | — | — |
| 11. New South Wales | — | — | — | — | — | — | — |
| 12. Nyassaland | — | — | — | — | — | — | — |
| 13. Rumania | — | — | — | 3,677 | 4,095 | — | — |
| 14. Spain | — | — | — | — | — | — | — |
| 15. United Kingdom (Ireland) | 6,055 | 11,020 | 2,269 | 5,859 | 3,449 | 5,158 | — |
| 16. U.S.A. | 210,241 | 521,308 | 139,550 | 309,600 | 522,690 | 347,570 | 316,540 |
| Total | | | | | | | |

* Bihargebirge. † Without Istria. ‡ Exports. § For 1918-1920.

A Long Ton = 2240 lb.
,, Metric ,, = 2204 ,,
,, Short ,, = 2000 ,,
,, Long ,, = 1·12 short tons
,, Metric ,, = 1·102 ,, ,,

A Long Ton = 1·0016 metric tons
,, Metric ,, = ·984 long ,,
,, Short ,, = ·907 metric ,,
,, Short ,, = ·809 long ,,

### Bauxite Production in U.S.A.

(In Long Tons.) (*The Mineral Industry*, 1924.)

| Year. | Georgia, Alabama, and Tennessee. | | Arkansas. | | Total. | |
|---|---|---|---|---|---|---|
| | Long Tons. | Value. (*b*) | Long Tons. | Value. (*b*) | Long Tons | Value. (*b*) |
| | | $ | | $ | | $ |
| 1914 . . | 24,071 | 92,508 | 195,247 | 976,686 | 219,318 | 1,069,194 |
| 1915 . . | 28,245 | 144,345 | 268,796 | 1,370,489 | 297,041 | 1,514,834 |
| 1916 . . | 49,190 | 284,810 | 375,910 | 2,011,590 | 425,100 | 2,296,400 |
| 1917 . . | 62,134 | 395,051 | 506,566 | 2,724,007 | 568,690 | 3,119,058 |
| 1918 . . | 42,829 | 314,112 | 562,892 | 3,133,880 | 605,721 | 3,447,992 |
| 1919 . . | 43,076 | 346,588 | 333,490 | 1,855,159 | 376,566 | 2,201,747 |
| 1920 . . | 40,029 | 349,453 | 481,279 | 2,897,892 | 521,308 | 3,247,345 |
| 1921 . . | 14,700 | 134,400 | 124,850 | 755,400 | 139,550 | 889,800 |
| 1922 . . | 42,810 | 329,440 | 266,790 | 1,682,890 | 309,600 | 2,012,330 |
| 1923 . . | 28,810 | 173,984 | 493,880 | 3,082,626 | 522,690 | 3,156,610 |
| 1924 . . | — | — | — | — | 347,570 | — |
| 1925 . . | 20,220 | — | 296,320 | — | 316,540 | 1,988,250 |

(*a*) Statistics of the U.S. Geol. Surv., by J. M. Hill. (*b*) Value, f.o.b. mines.

### Consumption of Bauxite in the United States (*a*).

| Year. | Production. | | | Imports. | | Consumption. | |
|---|---|---|---|---|---|---|---|
| | Long Tons. | Value. | Per Ton. | Long Tons. | Value. | Long Tons. | Value. |
| | | $ | $ | | $ | | $ |
| 1912 . | 160,124 | 900,620 | 5.00 | 26,214 | 95,413 | 186,079 | 864,363 |
| 1913 . | 210,241 | 997,698 | 4.75 | 21,456 | 85,746 | 231,697 | 1,083,444 |
| 1914 . | 219,318 | 1,069,194 | 4.87 | 24,844 | 96,500 | 238,788 | 925,610 |
| 1915 . | 297,041 | 1,514,834 | 5.10 | 3,420 | 17,107 | 284,379 | 814,755 |
| 1916 . | 425,100 | 2,296,400 | 5.40 | 30 | 87 | 407,191 | 1,309,033 |
| 1917 . | 568,690 | 3,116,421 | 5.48 | 7,691 | 28,989 | 554,590 | 1,824,121 |
| 1918 . | 605,721 | 3,447,992 | 5.69 | 3,653 | 14,791 | 589,663 | 1,939,095 |
| 1919 . | 376,566 | 2,201,747 | 5.85 | 6,082 | 36,820 | 364,947 | 866,473 |
| 1920 . | 521,308 | 3,247,345 | 6.23 | 42,895 | 408,485 | 541,946 | 1,655,033 |
| 1921 . | 139,550 | 889,800 | 6.38 | 27,587 | 164,589 | 161,195 | 565,604 |
| 1922 . | 309,600 | 1,935,800 | 6.25 | 23,656 | 93,805 | 313,639 | 1,144,927 |
| 1923 . | 522,690 | 3,156,610 | 6.04 | 119,020 | 593,882 | 563,150 | 3,401,426 |
| 1924 . | 347,570 | — | — | 201,974 | — | 472,479 | — |
| 1925 . | 316,540 | — | — | 353,696 | — | 591,666 | — |

(*a*) Statistics of U.S. Geol. Surv. (by J. M. Hill) and Bur. of Foreign and Domestic Commerce.

### WORLD'S PRODUCTION OF BAUXITE.

(During the war period.)

(*Long Tons.*)

| | 1913. | 1914. | 1915. | 1916. | 1917. | 1918. | 1919. |
|---|---|---|---|---|---|---|---|
| United Kingdom . . | 6,055 | 8,286 | 11,723 | 10,329 | 14,724 | 9,589 | 9,221 |
| British Guiana . . | — | — | — | — | 2,037 | 4,199 | — |
| India . . . . | 1,184 | 514 | 876 | 750 | 1,363 | 1,192 | 1,682 |
| France . . . . | 304,323 | — | 55,614 | 104,493 | 118,973 | — | 160,820 |
| Hungary . . . | — | — | 58,118 | — | — | — | — |
| Italy . . . . | 6,840 | 3,843 | 5,805 | 8,744 | 7,664 | 7,675 | 2,924 |
| Spain . . . . | — | — | — | — | — | 453 | 1,751 |
| United States . . | 210,241 | 219,318 | 297,041 | 425,100 | 568,690 | 605,721 | 376,566 |

### 3. Bauxite Exports.

(In Long Tons.) (*Imp. Min. Res. Bur.*)

| | 1913. | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|---|
| British Guiana . | — | 29,399 | 12,384 | — | 133,562 | 185,091 | 194,339 |
| Dutch Guiana . | — | — | — | — | 12,413 | 59,077 | 84,150 |
| France . . | — | 128,290 | 40,473 | 164,396 | — | — | — |
| Italy . . | — | — | — | — | — | — | — |
| Yugo-Slavia * . | — | — | — | — | — | — | — |
| United Kingdom (alumina) . | — | 6,907 | 407 | 3,548 | — | — | — |
| U.S.A. (including alumina) . | — | 22,257 | 5,942 | 19,617 | — | — | — |
| Total . | | | | | | | |

* The following letter, addressed to the Editor of *The Mining Journal* (see *The Mining Journal*, 27 February, 1926), is of interest in spite of its advertisement character :—

"Sir,—The correspondence which has appeared in recent issues of *The Mining Journal* on the subject of bauxite contains many interesting features, and further discussion should lead to results valuable both to producers of bauxite and to the users of the mineral.

"One field which is rapidly coming to the front is that in Dalmatia, near the Adriatic coast. During the war, about a quarter of a million tons were exported to the Central Empires. Since the war great interest has been taken in prospecting and preliminary work, and one company, the Adria Bauxite Company, is working and is giving a progressively increasing output, which in the latter part of 1924 and in 1925 amounted to 86,000 tons, and is expected to exceed 150,000 tons in 1926.

"There are other companies working in Yugo-Slavia which are not producing at present outside of the Jadranski Bauxite Company, in Spalato, controlled by the American Aluminium Company, which exported 4,000 tons to Norfolk in 1925, but it is hoped that they will reach the production stage in the near future.

"The Adria Bauxite Company exports to America and to Rotterdam (Neuhausen), and as its bauxite becomes better known will probably export to other consuming centres.

"Deep mining is being started to work the deeper deposits, and incline shafts are being driven, one of which has attained a depth of 90 metres on a gradient of 45 degrees.

"An interesting feature is the driving of stone drifts on the ancient line of unconformity between the Alveolinen Limestone and the Promina conglomerate of Eocene age. These drifts have developed large masses of bauxite, and regular outputs are being won. One drift of over 150 metres long has met several bauxite deposits.

"The reserves of bauxite of the Adria Bauxite Company are practically unlimited, and, together with those of the other companies, constitute one of the world's most important sources of supply and reserves for the future.

"The analysis so far delivered was on an average 20 per cent. water; 55 per cent. $Al_2O_3$ ; $TiO_2$, $SiO_2$, and loss 3 per cent. ; and 20 per cent. $Fe_2O_3$.

"The Adria Bauxite Company is now exporting a very high-grade ore, which gives an average analysis of 63 per cent. alumina with less than 1 per cent. silica. the low silica content being the Dalmatian speciality.—I am, dear sirs, yours very faithfully,

"T. L. Milic.

"Sibenik, Feb. 20."

### 4. Bauxite Imports.

(In Long Tons.) (*Imp. Min. Res. Bur.*)

| | 1913. | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|---|
| Canada (alumina) . | — | 52,737 | 7,346 | 34,748 | — | — | — |
| Norway (alumina) . | — | 15,550 | 12,063 | 11,604 | — | — | — |
| Switzerland . . | — | — | — | — | — | — | — |
| United Kingdom (alumina) . . . | — | 10,165 | 116 | 179 | — | — | — |
| U.S.A.* (crude bauxite and common blue clay). . | — | 48,961 | 31,262 | 27,415 | — | — | — |
| Total . . | | | | | | | |

* See Exports British Guiana.

### Bauxite Consumed by Various Industries in the U.S.A.*

(In Long Tons.)

| Year. | Aluminium. | Chemical. | Abrasive, etc. | Total. |
|---|---|---|---|---|
| 1920 . . . | 383,154 | 85,878 | 52,276 | 521,308 |
| 1921 . . . | 91,660 | 41,030 | 6,860 | 139,550 |
| 1922 . . . | 211,550 | 78,550 | 19,500 | 309,600 |
| 1923 . . . | 380,518 | 68,872 | 73,300 | 522,690 |
| 1924 . . . | 225,780 | 54,870 | 66,920 | 347,570 |
| 1925 . . . | 173,040 | 67,420 | 73,980 | 314,440 |

* Statistics of U.S. Geol. Surv., by J. M. Hill.

### 5-6. CRYOLITE PRODUCTION: EXPORTS.

(Long Tons.)

| | 1913. | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|---|
| Greenland . | 10·248 | 13,704 | 11,136 | 8,552 | 13,675 | 16,518 | 22,066 |

### 7. CRYOLITE IMPORTS.

(Long Tons.)

| | 1913. | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|---|
| Canada . . . | — | 772 | 95 | 618 | — | — | — |
| Czechoslovakia . | — | 103 | 94 | — | — | — | — |
| Denmark (crude) . | — | 8,380 | 6,020 | 4,918 | — | — | — |
| Norway . . | — | 4,525* | 204 | 711 | — | — | — |
| Japan . . . | — | 798 | 15 | 305 | — | — | — |
| U.S.A. . . . | — | 3,864 | 3,460 | 3,899 | — | — | — |
| Total . | | | | | | | |

* Bauxite chiefly.

### CRYOLITE RE-EXPORTS.

| | 1913. | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|---|
| Czechoslovakia . | — | 59 | 23 | — | — | — | — |
| Denmark (refined) . | — | 7,163 | 2,554 | 6,645 | — | — | — |
| Norway . . | — | — | 1,231 | — | — | — | — |
| Total . | | | | | | | |

CRYOLITE RE-EXPORTS FROM DENMARK TO

| | 1913. | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|---|
| United Kingdom . | — | 1,230 | 204 | 1,181 | — | — | — |
| France . . . . | — | 1,053 | 148 | 521 | — | — | — |
| Germany . . | — | 1,777 | 1,354 | 2,192 | — | — | — |
| Other countries . | — | 3,103 | 848 | 2,751 | — | — | — |
| Total . | | | | | | | |

## 8. ALUMINIUM PRODUCTION.

(Long Tons.) (*Imp. Min. Res. Bur.*)

| | 1913. | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|---|
| Austria . | — | 3,000 | 3,000 | 4,000 | 1,500 | 2,200 | — |
| Canada . | — | 10,000 | 3,000 | 9,000 | 12,000 | 8,000 | — |
| France . | — | 12,106 | 8,247 | 12,000 | 14,112 | 17,000 | 21,000 |
| Germany * . | — | 15,000 | 14,000 | 11,000 | 15,600 | 18,400 | 25,000 |
| Italy . | — | 1,218 | 732 | 797 | 1,449 | 2,025 | 1,800 |
| Norway † . | — | 7,000 | 5,000 | 6,000 | 13,105 | 19,632 | — |
| Switzerland . | — | 10,000 | 6,000 | 12,000 | 15,000 | 20,000 | — |
| United Kingdom . | — | 8,000 | 5,000 | 7,000 | 9,000 | 12,000 | — |
| U.S.A. ‡ . | — | 88,000 | 28,000 | 51,000 | 57,000 | 64,000 | 60,000 |
| Total . | | | | | | | |

* "An estimate of the world production of aluminium was given recently from an American source, which, according to 'Die Metallborse,' is not correct, inasmuch as it places the producing countries in the following order of importance: United States, Norway, Switzerland, France, and Germany. According to information collected by 'Die Metallborse,' the German production for 1925 will be found to be round 25,000 tons, while that for France is not more than 21,000 tons, and will probably be found to be about 20,500 tons. The German production in 1925 is about 6000 tons more than in 1924 and 9100 tons above that for 1923. The French production for 1925 shows only 2000 to 2500 tons increase over that of 1924.

"The considerable increase in the German production last year is stated to be due to the fact that the industry was free of strikes and other labour interruptions, which were considerable in 1924, and also to the production of the Innwerke plant, which came into operation early in September last. No reliable figures are available to show the output of the Innwerke, but from the fact that a special export tariff was granted the concern on the understanding that the aluminium exported for the three months ending with 1925 should not be less than 2500 tons, indicates that the

(*Notes continued on following page.*)

works are producing not less than 830 tons monthly for export, which corresponds to about 10,000 tons a year.

" With regard to the French production in 1925, this is likely to be considerably more in 1926, on account of the completion of the extension of the Froges works."
[*The Mining Journal*, 30 January, 1926.

† " Norwegian exports of aluminium during 1925 are given in a recent issue of ' Die Metallborse ' as follows, the 1924 figures being added for comparison :—

| Country. | 1925. M. Tons. | 1924. M. Tons. |
|---|---|---|
| Sweden | 927 | 905 |
| Germany | 2,258 | 1,682 |
| Netherlands | 722 | — |
| Belgium | 433 | 541 |
| Great Britain | 3,856 | 4,449 |
| Japan | 812 | 365 |
| United States | 6,681 | 7,471 |
|  | 15,689 | 15,413 |

" In December last the United States took 617 tons of aluminium from Norway and 1300 tons from Germany, while the total December exports of aluminium of the two countries amounted to 1777 tons for Norway and 1757 tons for Germany.

" The German exports of aluminium for 1925 are given officially as 7612 tons, apart from wares, of which the larger proportion was exported in the later months of the year, after the starting of production of the Innwerke in September. The capacity of the Innwerke is said to be about 10,000 tons of aluminium yearly, and it may be expected, therefore, that the surplus for export in the current year will be considerably more than in 1925.

" During 1925 Switzerland exported 17,393 tons of aluminium, compared with 15,659 tons in 1924. As is generally known, the aluminium produced in Switzerland is form pure alumina imported, the larger proportion of which has hitherto been supplied by Germany."—*The Mining Journal*, 27 March, 1926.

‡ " The value of new aluminium produced in the United States during 1925 was $36,430,000, a decrease of a little over 3 per cent. as compared with 1924, according to information furnished J. M. Hill, of the Bureau of Mines. The decrease was in part attributable to the drought in the Eastern States, which caused the shutting-down of two plants for some weeks. Virgin aluminium of 99 per cent. grade was quoted at 28 cents a lb., and the 98 per cent. grade at 27 cents a lb. until the last of October, when an advance of 1 cent was made in each grade. The price was reduced to 28 cents and 27 cents the first week of 1926. Aluminium bronze powder was used in increasing amounts for oil tank and interior shop painting, because of its high reflective and protective properties. Aluminium furniture was developed during 1925. The electrical industry still consumed large quantities of the metal, but the automobile industry remained the largest consuming industry.

" Imports (" general ") of aluminium metal, scrap, and alloy in 1925 increased nearly 48 per cent. as compared with 1924, reaching a total of 43,409,546 lbs., valued at $10,180,497, in 1925. Imports of plates, sheets, and bars, on the other hand, decreased 87 per cent., amounting to only 102,338 lbs., valued at $47,740, in 1925.

" Exports of aluminium ingots, scrap, and alloys in 1925 were 8,130,222 lbs., valued at $1,835,213, an increase of 142 per cent. as compared with exports in 1924. Exports of plates, sheets, bars, etc., in 1925 were over 50 per cent. greater than the quantity sent."—*The Mining Journal*, 3 April, 1926.

### ESTIMATED WORLD'S PRODUCTION OF ALUMINIUM.

(In Metric Tons.) (*Mineral Industry* for 1924.)

| Year. | Austria. | Canada. | France. | Germany. | Great Britain. | Italy. | Norway. | Switzer-land. | United States. | Total. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1913 . . . | 5,000 | 5,916 | (*a*) 13,503 | 800 | 10,000 | (*a*) 874 | 2,500 | 10,000 | 29,500 | 78,093 |
| 1914 . . . | 4,000 | 6,820 | (*a*) 9,967 | 800 | 8,000 | (*a*) 937 | 2,500 | 10,000 | 40,600 | 82,924 |
| 1915 . . . | 2,500 | 8,490 | (*a*) 6,020 | 2,000 | 6,000 | (*a*) 904 | 3,500 | 12,500 | 45,000 | 86,914 |
| 1916 . . . | 5,000 | 8,800 | (*a*) 9,604 | 8,000 | 4,000 | (*a*) 1,126 | 6,000 | 15,000 | 63,000 | 120,230 |
| 1917 . . . | 5,000 | 11,800 | (*a*) 11,066 | 15,000 | 6,000 | (*a*) 1,740 | 8,000 | 15,000 | 90,700 | 164,306 |
| 1918 . . . | 8,000 | 15,000 | (*a*) 12,023 | 25,000 | 14,000 | (*a*) 1,715 | 7,500 | 15,000 | 102,000 | 200,328 |
| 1919 . . . | 5,000 | 15,000 | (*a*) 10,255 | 15,000 | 10,000 | (*a*) 1,673 | 4,000 | 15,000 | 90,000 | 165,929 |
| 1920 . . . | 2,000 | 10,000 | (*a*) 12,304 | 10,000 | 8,000 | (*a*) 1,238 | 5,000 | 12,000 | 90,000 | 150,542 |
| 1921 . . . | 2,000 | 6,000 | 10,000 | 10,000 | 5,000 | (*a*) 744 | 4,000 | 10,000 | 28,750 | 76,494 |
| 1922 . . . | 4,000 | 9,000 | 12,000 | 12,000 | 9,500 | (*a*) 630 | 6,000 | 12,000 | 52,000 | 117,130 |
| 1923 . . . | 4,000 | 16,500 | 12,000 | 13,000 | 9,000 | 1,500 | 14,000 | 12,000 | 97,000 | 179,000 |
| 1924 . . . | — | — | — | — | — | — | — | — | — | — |
| 1925 . . . | — | — | — | — | — | — | — | — | — | — |
| Estimated capacity | 10,000 | 18,000 | 25,000 | 45,000 | 14,000 | 8,000 | 16,000 | 15,000 | 125,000 | 276,000 |

(*a*) Official figures.

ESTIMATED WORLD PRODUCTION OF ALUMINIUM, DISTRIBUTED BY PRODUCING COMPANIES.

(*Mineral Industry.*)

| Company. | Main Office. | Reduction Works in— | 1923. Output. Metric Tons. | 1924. Output. Metric Tons. | 1925. Output. Metric Tons. |
|---|---|---|---|---|---|
| Aluminium Company of America | Pittsburg, Pa. | United States, Canada (*a*), and Norway (*b*). | 101,000 | 93,000 | — |
| Northern Aluminium Company, Limited | Toronto, Canada. | Canada. | 16,500 | 16,000 | — |
| British Aluminium Company, Limited | London, England. | England, Scotland, and Norway. | 12,000 | 10,000 | — |
| Aluminium Corporation, Limited | Dolgarrog, Wales. | Wales. | 1,000 | 1,000 | — |
| L'Aluminium Française | Paris, France. | France, Switzerland, and Norway. | 17,000 | 28,500 | — |
| Aluminium-Industrie-Aktien-Gesellschaft | Neuhausen, Switzerland. | Switzerland, Austria, Germany. | 17,000 | 23,000 | — |
| German Government Works | Berlin, Germany. | Germany. | 13,000 | 12,000 | — |
| L'Aluminio Italiano | Rome, Italy. | Italy. | 1,500 | 2,000 | — |
|  |  | Total | 179,000 | 185,500 | — |

(*a*) Plant of subsidiary, Northern Aluminium Company, Limited, in Canada; output given under Canada.
(*b*) Plant of subsidiary, the former Norsk Aluminium Company, in Norway; output about 4000 metric tons.

### Estimated World's Production of Aluminium.

(*During the War Period.*)

(Long Tons.)

| | 1913. | 1914. | 1915. | 1916. | 1917. | 1918. | 1919. |
|---|---|---|---|---|---|---|---|
| United Kingdom . | 7,500 | 7,400 | 7,000 | 7,600 | 7,000 | 8,200 | 8,000 |
| Canada . . | 6,000 | 6,500 | 6,000 | 7,500 | 8,000 | 8,000 | 8,000 |
| Austria . . | 2,000 | 2,000 | — | — | — | — | — |
| France * . . | 13,283 | 9,803 | 5,920 | 9,447 | 10,886 | 11,826 | 12,000 |
| Germany . . | 1,000 | 1,000 | 1,000 | 8,000 | 20,000 | 25,000 | 12,000 |
| Italy * . . | 860 | 922 | 889 | 1,108 | 1,712 | 1,687 | 2,000 |
| Norway . . | 2,000 | 4,000 | 8,000 | 12,000 | 15,000 | 15,000 | 10,000 |
| Switzerland . | 10,000 | 15,000 | 10,000 | 12,500 | 15,000 | 15,000 | 15,000 |
| United States . | 29,000 | 41,500 | 44,500 | 62,500 | 80,000 | 85,000 | 80,000 |
| Total . | 71,643 | 88,125 | 83,309 | 120,655 | 157,598 | 169,713 | 147,000 |

* Official figures. 1919 figure estimated.

### 9. Aluminium Exports.

(Long Tons.)

| | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|
| UNITED KINGDOM— | | | | | | |
| Ingots, blocks, etc. | 9,542 | 3,190 | 5,026 | 4,730 | 2,966 | 3,717 |
| Plates, sheets, bars, etc. . . . | 3,527 | 1,058 | 1,326 | 1,240 | 1,512 | 2,286 |
| CANADA— | | | | | | |
| Ingots, blocks, bars, sheets, etc. . . | 6,252 | 2,692 | 6,480 | 6,960 | 10,113 | 10,968 |
| AUSTRIA— | | | | | | |
| Crude aluminium . | 593 | 492 | — | 1,879 | 2,240 | 1,990 |
| FRANCE— | | | | | | |
| Ingots or scrap . | 1,213 | 308 | 1,810 | 319 | 240 | 2,104 |
| Beaten, rolled or drawn aluminium, etc. . | 1,382 | 277 | 210 | 888 | 671 | 1,140 |
| GERMANY— | | | | | | |
| Crude aluminium . | 2,894 | 700 | 441 | 195 | 1,128 | 4,266 |
| Beaten or rolled aluminium . | 1,322 | 1,071 | 2,311 | 3,051 | 3,566 | 3,223 |
| ITALY— | | | | | | |
| Crude aluminium . | 549 | 1,300 | 339 | 153 | 2 | 15 |
| Sheets, bars, etc. . | 123 | 18 | 10 | 43 | 41 | 50 |
| NETHERLANDS— | | | | | | |
| Crude aluminium . | 65 | 55 | 310 | 163 | 234 | 203 |
| NORWAY— | | | | | | |
| Ingots . . | 5,527 | 6,166 | 6,078 | 12,573 | 18,866 | 20,218 |
| Sheets . . | | 42 | 139 | 122 | 87 | 102 |
| SWITZERLAND— | | | | | | |
| Blocks, ingots, etc.— | | | | | | |
| Pure . . . | 4,683 | 6,514 | 6,086 | 9,253 | 12,364 | 13,639 |
| Alloyed . . | 237 | 313 | 960 | 530 | 878 | 1,476 |
| Bars, sheets, tubes, etc. . . . | 521 | 1,174 | 1,377 | 1,471 | 1,143 | 990 |
| UNITED STATES— | | | | | | |
| Ingots and alloys . | 3,295 | 470 | 687 | 522 | 1,499 | 3,630 |
| Plates and sheets . | 904 | 511 | 1,254 | 1,951 | 1,333 | 2,014 |

## 10. ALUMINIUM IMPORTS.

(Long Tons.)

| | 1920. | 1921. | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|
| UNITED KINGDOM— | | | | | | |
| Ingots, blocks, etc. | 6,577 | 827 | 821 | 2,397 | 9,605 | 10,062 |
| Plates, sheets, bars | 907 | 619 | 1,389 | 2,801 | 2,607 | 2,189 |
| CANADA— | | | | | | |
| Ingots, blocks, bars | 744 | 316 | 480 | 313 | 262 | 319 |
| INDIA— | | | | | | |
| Ingots, blocks, bars | 907 | 154 | 460 | 371 | 254 | 162 |
| Circles | 1,562 | 1,657 | 2,867 | 3,289 | 3,743 | 3,589 |
| Sheets | 449 | 156 | 147 | 195 | 145 | 195 |
| BELGIUM— | | | | | | |
| Crude aluminium | 379 | 360 | 506 | 887 | 1,021 | 990 |
| Sheets | 38 | 35 | 61 | 89 | 532 | 563 |
| Simply cast aluminium | 12 | 4 | 4 | 4 | | |
| Beaten, rolled ,, | 139 | 199 | 283 | 550 | | |
| FRANCE— | | | | | | |
| Ingots and scrap | 1,264 | 211 | 306 | 1,232 | 1,032 | 113 |
| Beaten, rolled or drawn aluminium | 112 | 184 | 111 | 198 | 256 | 140 |
| GERMANY— | | | | | | |
| Crude aluminium | 7,696 | 1,312 | 3,610 | 5,359 | 5,383 | 10,545 |
| Beaten or rolled aluminium | 90 | 15 | 15 | 7 | 48 | 187 |
| ITALY— | | | | | | |
| Crude aluminium | 510 | 11 | 122 | 1,853 | 2,730 | 6,400 |
| Sheets, bars, etc. | 69 | 85 | 100 | 85 | 157 | 178 |
| SWEDEN— | | | | | | |
| Crude aluminium | 655 | 51 | 327 | 613 | 1,068 | 1,121 |
| Sheets and strips | 128 | 69 | 38 | 174 | 109 | 164 |
| SWITZERLAND— | | | | | | |
| Blocks, ingots, etc.— | | | | | | |
| Pure | 942 | 655 | 36 | 70 | 74 | 361 |
| Alloyed | 125 | 42 | 57 | 45 | 42 | 41 |
| Bars, sheets, etc. | 534 | 202 | 40 | 56 | 81 | 31 |
| UNITED STATES— | | | | | | |
| Crude aluminium | 17,827 | 13,615 | 17,760 | 19,225 | 13,122 | 19,379 |
| JAPAN— | | | | | | |
| Aluminium | 1,937 | 1,810 | 3,934 | 3,625 | 4,121 | 4,612 |

## 11. ALUMINIUM SALTS.

### UNITED STATES PRODUCTION AND IMPORTS OF ALUMINIUM SALTS.*

*(In Short Tons.)*

| Years. | Production. | | | | | | Imports.† | |
|---|---|---|---|---|---|---|---|---|
| | Alum. | | | Aluminium Sulphate. | | | | |
| | Quantity. | Value. | Per Ton. | Quantity. | Value. | Per Ton. | Quantity. | Value. |
| | | $ | $ | | $ | $ | | $ |
| 1913 | 9,605 | 312,822 | 23.57 | 157,749 | 2,977,708 | 18.88 | 2,702 | 66,549 |
| 1914 | 18,238 | 565,989 | 31.03 | 164,954 | 2,942,572 | 17.84 | 2,891 | 73,028 |
| 1915 | 24,915 | 699,256 | 28.07 | 169,153 | 3,224,495 | 19.06 | 1,408 | 34,320 |
| 1916 | 27,257 | 1,177,881 | 43.21 | 153,860 | 4,410,741 | 28.67 | 1,247 | 68,660 |
| 1917 | 19,714 | 1,017,083 | 51.60 | 178,738 | 5,746,472 | 32.15 | 507 | 39,088 |
| 1918 | 20,286 | 1,051,449 | 51.83 | 209,079 | 6,473,086 | 30.96 | 231 | 18,519 |
| 1919 | 17,019 | 879,198 | 51.66 | 200,034 | 6,763,063 | 33.80 | 343 | 21,877 |
| 1920 | 16,824 | 992,259 | 58.98 | 229·888 | 8,104,457 | 35.30 | 1,340 | 69,896 |
| 1921 | 12,220 | 755,500 | 61.82 | 165,920 | 6,117,200 | 36.87 | 1,009 | 45,963 |
| 1922 | 17,811 | 1,106,130 | 62.11 | 231,387 | 6,090,166 | 26.32 | 2,889 | 116,971 |
| 1923 | 12,827 | 792,164 | 61.76 | 246,095 | 6,354,315 | 25.82 | 2,818 | 120,663 |

* Statistics of U.S. Geol. Surv. (by J. M. Hill), and Bur. of Foreign and Domestic Commerce.

† Includes alumina, aluminium hydrate, or refined bauxite, alum, alum cake, aluminium sulphate, aluminous cake, and alum in crystals or ground.

(Statistics by J. M. Hill.)

INDIAN IMPORTS OF ALUMINIUM AND ALUMINIUM SALTS, PERIOD 1913-1925.

| | | 1913. | 1914. | 1915. | 1916. | 1917. | 1918. | 1919. | 1920.* | 1921.* | 1922. | 1923. | 1924. | 1925. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aluminium Ingots | cwts. | — | 1,737 | 1,799 | 4 | 29 | 6,514 | 5,486 | 23,190 | 1,197 | 8,872 | 9,909 | 3,690 | 4,164 |
| | £ | — | 7,528 | 8,198 | 48 | 190 | 110,025 | 67,356 | 195,999 | 12,240 | 42,102 | 48,661 | 19,284 | 20,872 |
| Total Aluminium | cwts. | 28,572 | 21,732 | 17,563 | 763 | 841 | 8,092 | 13,582 | 64,468 | 35,531 | 76,605 | 79,722 | 91.541 | 89,571 |
| | £ | 151,271 | 120,459 | 106,401 | 7,212 | 15,279 | 157,462 | 208,065 | 767,122 | 568,452 | 604,322 | 520,987 | 647,869 | 652,652 |
| Alum | cwts. | Included with aluminium sulphate. | | | | | 3,037 | 51,915 | 85,561 | 38,235 | 73,226 | 68,094 | — | — |
| | £ | | | | | | 11,073 | 66,501 | 101,827 | 53,811 | 58,347 | 45,862 | — | — |
| Aluminium sulphate | cwts. | 97,931 | 75,093 | 97,105 | 101,118 | 79,768 | 65,089 | 64,312 | 100,351 | 47,272 | 57,681 | 56,275 | 67,898 | 48,425 |
| | £ | 30,086 | 24,774 | 44,534 | 59,460 | 70,442 | 75,984 | 47,304 | 76,528 | 44,381 | 31,025 | 26,622 | 25,732 | 12,623 |

* Rs. 10 = £1.

PRICES: (1) UNITED KINGDOM.

*(Monthly Average London Market Prices of Aluminium per Long Ton.)*

| Month. | Aluminium (98-99 per cent.). Home. | | | | Aluminium (98-99 per cent.). Export | | | |
|---|---|---|---|---|---|---|---|---|
| | 1920. | 1921. | 1922. | | 1920. | 1921. | 1922. | 1923. |
| | £ | £ | £ | | £ | £ | £ | |
| January . | 155 | 165 | 100 | | 166 | 165 | 120 | |
| February . | 165 | 156 | 100 | | 173 | 160 | 105 | |
| March . . | 165 | 150 | 100 | | 179 | 155 | 105 | |
| April . . | 165 | 150 | 100 | | 185 | 150 | 105 | |
| May . . | 165 | 150 | 100 | | 185 | 150 | 105 | |
| June . . | 165 | 150 | 100 | | 185 | 150 | 100 | |
| July . . | 165 | 150 | 100 | | 185 | 150 | 100 | |
| August . | 165 | 122 | 95 | | 185 | 131 | 100 | |
| September . | 165 | 123 | 95 | | 185 | 125 | 100 | |
| October . | 165 | 120 | 95 | | 185 | 125 | 105 | |
| November . | 165 | 120 | 95 | | 185 | 125 | 105 | |
| December . | 165 | 120 | 100 | | 170 | 125 | 105 | |
| Average for the year . | 164 | 140 | 98 | | 181 | 143 | 106 | |

2. FRANCE.

*(Monthly Average Paris Market Prices of Bauxite and Aluminium.)*

| Month. | Bauxite (60 per cent. Alumina) (*a*) per metric ton (f.o.b. Mediterranean Port). | | | | Aluminium (98-99 per cent.) (*d*) per kilogram. | | | |
|---|---|---|---|---|---|---|---|---|
| | 1920. | 1921. | 1922. | | 1920. | 1921. | 1922. | 1923. |
| | Francs. | Francs. | Francs. | | Francs. | Francs. | Francs. | |
| January . . | (*b*) | 50 | 54 | | 6·25 | 8·78 | 6·50 | |
| February . | (*b*) | 50 | 54 | | 7·35 | 8·50 | 6·50 | |
| March . . | (*b*) | 42 | 54 | | 8·90 | 8·50 | 6·50 | |
| April . . | (*b*) | 42 | 54 | | 8·90 | 7·83 | 6·50 | |
| May . . | (*b*) | 44 | 54 | | 10·00 | 7·17 | 6·50 | |
| June . . | (*b*) | 48 | 54 | | 10·50 | 6·33 | 6·50 | |
| July . . | (*b*) | 48 | 54 | | 10·50 | 5·00 | 6·50 | |
| August . . | (*b*) | 48 | 54 | | 10·50 | 6·00 | 6·50 | |
| September . | 60 (*c*) | 48 | 54 | | 10·50 | 6·50 | 6·50 | |
| October . . | 60 (*c*) | 48 | 54 | | 10·50 | 6·50 | 6·50 | |
| November . | 60 (*c*) | 60 | 54 | | 10·50 | 6·50 | 6·50 | |
| December . | 50 | 60 | 58 | | 9·35 | 6·50 | 6·50 | |
| Average for the year . . | (*b*) | 49 | 54 | | 9·48 | 7·01 | 6·50 | |

(*a*) Three per cent. silica from September, 1920, to middle of May, 1921; 5 per cent. silica from middle of May, 1921, to end of 1921; and 6 per cent. silica during 1922.

(*b*) Information not available.

(*c*) At the mine.

(*d*) Until the beginning of April, 1921, quotations were for immediate delivery

### 3. United States.

(*Monthly Average New York Market Prices of Bauxite and Aluminium.*)

| Month. | American bauxite, f.o.b. shipping point, per gross ton. |  |  |  |  |  | Aluminium, No. 1 Virgin (98-99 per cent.), per lb. |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | Crushed and dried. |  | Pulverised and dried. |  | Calcined, crushed. |  |  |  |  |
|  | 1921 (*a*) | 1922. | 1921 (*a*) | 1922. | 1921 (*a*) | 1922. | 1920. | 1921. | 1922. |
|  | Dollars. | Dollars. | Dollars. | Dollars. | Dollars. | Dollars. | Cents. | Cents. | Cents. |
| January | (*a*) | 9.00 | (*a*) | 13.50 | (*a*) | 20.00 | 32.00 | 22.86 | 17.74 |
| February | (*a*) | 8.00 | (*a*) | 13.25 | (*a*) | 20.50 | 31.83 | 24.50 | 17.33 |
| March | (*a*) | 7.00 | (*a*) | 13.00 | (*a*) | 21.00 | 31.50 | 23.44 | 17.52 |
| April | (*a*) | 7.00 | (*a*) | 13.00 | (*a*) | 21.00 | 31.61 | 23.25 | 18.07 |
| May | (*a*) | 7.50 | (*a*) | 13.00 | (*a*) | 23.50 | 31.95 | 23.06 | 17.92 |
| June | 9.00 | 7.50 | 13.50 | 13.00 | 20.00 | 23.50 | 32.00 | 22.75 | 17.87 |
| July | 9.00 | 7.50 | 13.50 | 13.00 | 20.00 | 23.50 | 32.00 | 22.63 | 17.87 |
| August | 9.00 | 7.50 | 13.50 | 13.00 | 20.00 | 23.50 | 32.21 | 20.22 | 17.87 |
| September | 9.00 | 7.50 | 13.50 | 13.00 | 20.00 | 23.50 | 31.44 | 19.02 | 18.26 |
| October | 9.00 | 7.50 | 13.50 | 13.00 | 20.00 | 23.50 | 29.12 | 17.85 | 20.32 |
| November | 9.00 | 7.50 | 13.50 | 13.00 | 20.00 | 23.50 | 27.80 | 17.50 | 20.87 |
| December | 9.00 | 7.50 | 13.50 | 13.00 | 20.00 | 23.50 | 23.83 | 17.50 | 20.52 |
| Average for the year | 9.00(*b*) | 7.58 | 13.50(*b*) | 13.06 | 20.00(*b*) | 22.54 | 30.61 | 21.22 | 18.68 |

(*a*) Information not available for 1920 and January-May, 1921.
(*b*) Average for seven months only.

# CHAPTER XII.

## BIBLIOGRAPHY.

The bibliography has been divided into two parts—(I) an index to the following subjects: Aluminium, Bauxite, Cryolite, Laterite, and Terra Rosa, in which are merely given the names of authors; and (II) the main bibliography, giving the various publications in alphabetical order of authors' names.

## PART I.

### Aluminium.

*(Alphabetical List of Authors.)*

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### Bauxite.

*(Geographical Index to Authors.)*

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**Alabama.**—W. M. Brewer, G. H. Clark, J. M. Hill, W. F. Hillebrand, H. McCalley (see U.S.A.).
**Antrim.**—See Ireland.
**Aquila.**—C. Formenti (see Italy).
**Ariege.**—A. Daubrée (see France).
**Arkansas.**—F. W. B. Berger, J. C. Branner, J. M. Hill, R. B. Ladoo, T. Shiras, D. C. Wysor.
**Austria (Styria).**—E. Drechsler, M. Lill, G. Schnitzer.
**Bihar and Orissa.**—L. L. Fermor, C. S. Fox.
**Bihargebirge (Rumania).**—F. Beyschlag, B. de Horvath, R. Lachmann, O. Pauls, B. Lotti, Puscarin, Szádeczky.
**Bombay Presidency.**—A. T. Arnall, C. S. Fox, H. C. Jones.
**Bosnia.**—F. Kerner-Marilaun, Kišpatić, F. Katzer.
**Bouches du Rhone.**—See France.
**British Columbia.**—R. Dunn.
**British Guiana.**—W. Egerton, L. T. Emory, J. B. Harrison.
**Carniola (Yugo-Slavia).**—A. Fleckner.
**Central Provinces.**—W. R. Dunstan, L. L. Fermor, C. S. Fox.

**Croatia.**—F. Kerner-Marilaun, M. Kišpatić.
**Dahomey (Togoland).**—T. Robertson.
**Dalmatia.**—C. Crema, F. Kerner-Marilaun, L. T. Milic.
**Dutch Guiana.**—F. O. Dentz, L. T. Emory.
**France.**—Arsandaux, Augé, P. Berthier, A. Carnot, L. Collot, H. Coquand, V. D'Aoust, St. Claire Deville, L. Dieulafait, G. Fabre, A. Lacroix, L. Roule, L. Saemen.
**French Guiana.**—E. Jannettaz, A. Lacroix.
**French Guinée.**—W. Henatsch.
**French Togoland.**—A. E. Kitson.
**Georgia (U.S.A.).**—C. W. Hayes, J. M. Hill, S. W. McCallie, H. K. Shearer, H. Watkins, T. L. Watson.
**Germany (Vogelsberg).**—H. Harrassowitz, Hüffner, E. K. Judd, E. Kaiser, J. R. Kilroe, Kobrich, Landgraeber, Liebrich, Münster, A. Strenge.
**Gold Coast.**—A. E. Kitson.
**Greece.**—A. A. Damour.
**Gwalior.**—S. M. Mehta.
**Herault.**—A. Daubrée, P. de Rouville (see France).
**Herzgowina.**—F. Kerner-Marilaun, M. Kišpatić, F. Katzer.
**Hesse.**—See Vogelsberg, Germany.
**Hungary.**—See Bihargebirge, Rumania.
**India.**—A. T. Arnall, G. S. Blake, R. C. Burton, W. R. Dunstan, L. L. Fermor, C. S. Fox, T. H. Holland, H. Warth.
**Ireland.**—G. G. Blackwell, G. A. J. Cole, G. H. Kinahan, W. Peile, H. Seger, R. G. Symes, C. H. Williams.
**Istria.**—C. Crema, F. Kerner-Marilaun, Leininen, B. Lotti, A. Polley.
**Italy.**—Aichino, M. Casetti, G. D'Achiardi, C. Formenti, B. Lotti, C. Martelli, W. Mattirolo, Novarese.
**Jammu (Kashmir).**—C. S. Fox.
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**Spain.**—J. R. Calataynd, J. Calafat, J. E. N. Gatataynd, H. Sampelayo.
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**Malay Peninsula.**—J. R. Logan, J. B. Scrivenor.

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*(Index to Authors.)*

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## PART II.

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    (ii) On the proportion of contained iron;
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The third member consists in the east of layers of red clay, sandstone, etc. In Provence the upper beds contain species of Physa, Lymnæa, and Planorbis, existing genera of pond and marsh snails. . . . The same interruption of the marine series between the Cretaceous and Eocene is repeated in the region north and east of the Adriatic ; . . . from Carinthia, through Istria, the islands of the Quarnero and a great part of Dalmatia, a varied group of intercalated brackish or fresh water beds appears on the horizon. Near Sebenico the fresh water limestone rests on an eroded surface of the Cretaceous limestone Liburnian Stage.

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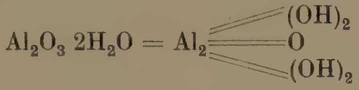

$$Al_2O_3\ 2H_2O = Al_2 \begin{matrix} \diagup (OH)_2 \\ = O \\ \diagdown (OH)_2 \end{matrix}$$

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